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CRYOFRACTURE DEMILITARIZATION OF MUNITIONS (PHASE I)

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The U.S. Army has been tasked with the responsibility of overseeing the demilitarization of obsolete munitions currently in the stockpile. In support of this activity, efforts are underway to develop technologies which will accomplish the demilitarization in a safe and environmentally friendly manner. The use of cryofracture to accomplish this task for small explosive loaded munitions is one of the technologies being developed.

This report details the results of tests conducted on M42/M46/M77 submunition grenades and M61/ M67/M69 hand grenades to determine the feasibility of using cryofracture to demilitarize these munitions. Prior to conducting tests using live grenades, inert grenades--where available--were used to establish parameters such as the acceptable time in the cryobath and the crush height of the press. The report also contains concepts and preliminary cost estimates for a production demilitarization facility using cryofracture technology.

14. SUBJECT TERMS

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Munitions	Liquid nitrogen	Robot

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INTRODUCTION AND SUMMARY

Introduction

A cryofracture process was developed and successfully tested on small, fully assembled, explosive-loaded munitions items. Cryofracture involves the freezing of the munitions in a liquid nitrogen (LN_2) bath, followed by fracture of the embrittled item(s) in a hydraulic press, and the subsequent thermal treatment of the fractured munition debris in order to destroy the explosives and decontaminate any residual metal parts (which may be recovered for scrap value). Because cryofractured debris burns rather than detonates, cryofracture significantly increases the rate at which items such as grenades can be demilled by eliminating item detonation which sometimes occurs when they are subjected to a thermal destruction process. Thus, in addition to increasing throughput, reduced hazard to both the equipment and personnel during thermal destruction is an inherent benefit of the cryofracture process. Process development and testing to date was conducted at the Munitions Cryofracture Test Facility located at Dugway Proving Ground (DPG) in Utah. Testing was conducted on three types of munitions in order to establish cryofracture process parameters such as munition cool-down time, press tooling configuration, and press closure; provide confidence that the process could be carried out in a safe, repeatable manner; and develop data for the design of a prototype production cryofracture demilitarization facility. Items tested included M42/M46/M77 submunition grenades and M61/M67 hand grenades. After a number of inert tests to establish initial process operating parameters, a total of 1,084 grenades were cryofractured: 433 M77's in 26 press fractures, 330 M67's in 29 press fractures, and 321 M61's in 61 press fractures. Up to 45 M42/M46/M77's were processed in a single batch press fracture with the limit being 16 for the larger M61 and M67 hand grenades. While some problems were encountered (mainly with the M61's), the results of the testing to date have overwhelmingly demonstrated the value of the process and its maturity for prototype implementation. A design concept for a production facility using existing equipment has been completed.

During previous development of the cryofracture process, a number of tests involving handling and cryofracture of explosively configured munitions were conducted at the Munitions Cryofracture Test Facility at DPG. The purpose of these tests was to demonstrate the feasibility of the cryofracture process for chemical munitions. These tests successfully demonstrated that explosively configured, agent simulant filled munitions could be handled, cryocooled, and cryofractured without explosive events. Over 3,600 explosively configured munitions were successfully cryofractured. Table 1 summarizes the type and quantity of munitions cryofractured along with the packaging for each munition type.

The purpose of the latest series of tests, as documented in this report, was to use the Munitions Cryofracture Test Facility to demonstrate the feasibility of the cryofracture process for conventional munitions, with emphasis on munitions that are difficult to disassemble. A Test Plan (ref 1) and a Safety Assessment/Preliminary Hazard Analysis (ref 2) were prepared to establish a basis for all testing.

Summary of Testing

M42/M46/M77 Grenades

A series of 30 cryofractures of inert M42/M46 grenades were initially performed to establish the parameters to be used in subsequent live grenade cryofractures. A total of 267 grenades were cryofractured. These inert tests demonstrated the following:

- Good brittle fractures and explosive simulant accessing with minimal disturbance of the grenade fuzes.
- Short cool-down time. Acceptable cool-down duration as low as 6 min. was demonstrated.
- Reasonable margin of out-of cryobath warm-up time prior to fracture. Warm-up time of up to 2 min. was demonstrated.
- Reasonable packing for multiple grenade fractures.
- The ability of the press to cryofracture up to 45 grenades in a single fracture.

A total of 26 cryofractures of live M77 grenades were then successfully performed to demonstrate the feasibility of the cryofracture process for this munition. Two series of tests were performed. The first series of 16 cryofractures demonstrated that M77 grenades could be cryocooled, robotically handled, and cryofractured with good explosive accessing and no explosions during the fracture process. A total of 423 grenades were processed with no explosions during cryocooling, robotic handling, or fracture operations. The detonator from each grenade initiated with a pop during debris burning in the open grate furnace. A single grenade exploded in the furnace following the eighth cryofracture. After adjustment of the fracture parameters, no further furnace explosions occurred during the cryofracture of the remaining 352 grenades. A second series of 10 cryofractures (10 grenades total) was performed to determine the press closure spacing limits necessary to avoid explosions during the fracture. It was determined that the grenades will not explode during the fracture if the press closure spacing (crush height) is 0.75 in. or greater. The selected parameters for the cryofracture of M77 grenades were as follows:

- Cool-down time - 10 min.
- Press closure spacing - 1.18 in.
- Grenade spacing - 0.5 in. end-to-end and 0.25 in. side-to-side

Data sheets for M42 and M46 grenades are presented in appendix A.

M69/M67 Hand Grenades

A series of 20 cryofractures of inert "practice" M69 hand grenades were performed to establish the parameters to be used in subsequent live M67 hand grenade cryofractures. A total of 103 M69 hand grenades were cryofractured. These inert tests demonstrated the following:

- Good brittle fractures and explosive simulant accessing with minimal disturbance of the grenade fuzes.
- Short cool-down time. Acceptable cool-down duration as low as 6 min. was demonstrated.
- Reasonable margin of out-of cryobath warm-up time prior to fracture. Warm-up time of up to 2 min. was demonstrated.
- Reasonable packing for multiple grenade fractures.
- The ability of the press to cryofracture up to 16 hand grenades in a single fracture.

A series of 29 cryofractures of live M67 hand grenades successfully demonstrated the feasibility of the cryofracture process for this munition. A total of 330 hand grenades were processed with no explosions during cryocooling, robotic handling, or fracture operations. The detonator from each hand grenade usually initiated during debris burning in the open gate furnace. On seven of the 29 tests, explosions judged to involve not only the grenade detonator(s) but also some quantity of primary explosive occurred during debris burning. While it is uncertain whether these explosions would occur if the debris was fed to a rotary kiln instead of an open grate furnace, the intensity of these explosions was judged to be acceptable for a rotary kiln. The selected parameters for the cryofracture of M67 hand grenades were as follows:

- Cool-down time - 10 min.
- Press closure spacing - 2.0 in.
- Grenade spacing - zero end-to-end and zero side-to-side

Data sheets for M67 and M69 hand grenades are presented in appendix A

M61 Hand Grenades

A series of 61 cryofractures of live M61 hand grenades were performed. Inert M61 hand grenades were not available and therefore the workup tests to establish the

cryofracture parameters were performed with live grenades. A total of 321 hand grenades were processed. No explosions occurred during cryocooling and robotic handling operations, but three explosions occurred in the press tooling during fracture. Two of the three press tooling explosions were low level, produced no damage, and had no effect on facility operations. The third was stronger and resulted in measurable damage to the press tooling, the press honeycomb structure, the press discharge chute, and the fragment cart. In three tests, explosions also occurred in the fragment cart after dumping the cryofractured debris into the open grate furnace. Explosive debris that was retained in the fragment cart after the dump was set on fire by the open grate furnace. The in-cart fire then initiated one or more detonators and other nearby explosive material. The fragment cart was subsequently modified and successfully demonstrated excellent debris removal and no further in-cart explosions.

There were also a number of explosions in the open grate furnace during the burning of the cryofractured debris. Many of these explosions were judged to involve not only the grenade detonator(s) but also some quantity of the primary explosive. It is uncertain whether these explosions would occur if the debris was fed to a rotary kiln instead of an open grate furnace. The M61 hand grenade tests demonstrated the following:

- Reliable cryofracture of M61 hand grenades is difficult and will require further work if the cryofractured debris is to be incinerated. The steel fragmentation coil within the grenade is believed to limit the breakup of the grenade during the fracture.

- Short cool-down time. Acceptable cool-down duration as low as 8 min. was demonstrated.

- Reasonable packing for multiple grenade fractures.

- A press closure spacing of at least 1.25 in., and possibly greater, is required to avoid explosions during the fracture.

A data sheet for the M61 hand grenade is presented in appendix A.

TEST FACILITY DESCRIPTION

The Munitions Cryofracture Test Facility is located at DPG in Utah. The vicinity map in figure 1 locates DPG relative to Salt Lake City. Figure 2 shows the overall arrangement of the test facility and its primary equipment. The major piece of equipment, around which the other equipment is located, is a hydraulic press. A munitions handling robot is located adjacent to the press and a track-mounted cryobath is located adjacent to the robot (fig. 3). The cryobath moves on its track to permit the robot to reach all locations in the bath. All

munitions handling operations relative to moving the munitions into or out of the cryobath, the press, or the open grate furnace, are designed to be performed remotely. Test operations (for live munitions) are controlled by personnel located in a remotely located control station. Close circuit television (CCTV) cameras installed at key positions provide test personnel with visual confirmation that the critical steps in the test operation are performed successfully. A supervisory computer monitors and controls all mechanical components and collects all required data.

A used 750 ton Erie hydraulic press was purchased and modified for use in the test facility. Modifications included extending each of the four posts 22 in. to increase the daylight to 106 in., replacing the flat bed press base with a new base with a central opening for discharge of cryofractured debris, and modifying the press slide to permit attachment of an explosive containment chamber (ECC) assembly. A custom designed conical discharge chute attaches to the underside of the press base.

The purpose of the ECC assembly is to protect the press and other equipment from fragments and to protect the press hydraulics in the unexpected event of an explosion during fracture operations. Figure 4 shows the configuration of the press ECC components. When a munition is fractured, the two steel rings enclose the munition and press tooling.

The custom designed cryobath is rail mounted to permit movement relative to the munitions handling robot. The cryobath translation mechanism consists of a motor driven sprocket and a fixed chain. The motor and speed reducer produce an approximately constant translation speed of 4 ft/min. The 750:1 speed reducer also acts as a brake to prevent movement when the cryobath is not being driven. Limit switches are used to automatically position the cryobath for robotic loading and unloading of munitions. A munitions loading platform allows placement of the munitions for pickup by the robot. Figure 5 shows loaded munitions in position on the cryobath loading platform. The cryobath has a capacity of up to 1,400 gal. of LN_2. LN_2 is stored in a 6,000 gal. tank located outside the building.

Munitions are loaded into the cryobath and then removed from the cryobath and placed in the press tooling by a PRAB Model FC robot. This robot was also purchased, used, and refurbished for use in the test facility. The robot uses an end effector designed to pick up custom grenade handling baskets. The munitions are manually loaded into the handling baskets and then onto the cryobath loading platform. All subsequent explosively configured munitions handling operations are performed remotely with no personnel in the test facility building.

Following fracture in the press, munition, and basket fragments drop into a custom designed chain-driven fragment cart (fig. 6). The remotely actuated fragment cart transports the fragments to the open grate furnace.

The custom designed open grate furnace is a two million BTU/hr, propane fueled, forced air unit (fig. 7). A centrifugal blower supplies combustion and excess air. The open grate contains a movable basket that permits the remote extraction of metal fragments after burning (fig. 8). The furnace grate is made up of three layers of grating material. The top two carbon steel grates are intended to provide a stand-off of burning material from the bottom Hastelloy X grate. The top two grates can be easily replaced if damage occurs. The fragments are dumped into scrap containers. Metal fragments are buried in a landfill after testing to verify that all explosives have been destroyed. Two 1,000 gal. tanks and a vaporizer supply propane to the furnace.

The press, robot, and cryobath are housed in a 50 ft x 50 ft metal building (fig. 9). The building is heated and air conditioned. Six CCTV cameras are installed at key positions in the facility to provide test personnel with visual confirmation that the critical steps in the test operations are performed successfully. Electric power for the building is provided by a 200 kW diesel generator.

Operational control and data acquisition is performed by a supervisory computer located in a 40 ft trailer. The control center trailer is located behind an earthen berm approximately 600 ft from the test facility building. The supervisory computer, a Data General MV/2000, supports a multiprocessing/multitasking environment for real-time process control. The computer is interfaced to the facility via shielded cables. A nine track tape drive is used for data archival. The control center trailer also houses CCTV monitors, VCRs, control terminals, graphic display terminals, and supporting printers. Electrical power for the control center is provided by an 80 kW diesel generator. The supervisory computer controls and monitors the process (cryobath, robot, press, fragment cart, and furnace), collects the required data, and monitors a variety of alarms. All process events are recorded on a printer with time and date stamps which log all operations. The graphic displays provide operators real-time displays of process values and graphs of process trends.

TEST ARTICLE DESCRIPTION

Munitions

The type and quantity of munitions cryofractured are summarized in table 3.

Table 4 lists the characteristics of each munition type. Additional description information is presented in appendix A. The inert M42/M46 grenades contained safety clips but did not contain safety pins or nylon ribbon stabilizers. The live M77 grenades contained safety clips, safety pins, and nylon ribbon stabilizers. All munitions were supplied by the Government and delivered to DPG by the Government.

Press Tooling

Press tooling originally developed for M23 mine drums [drawing 029787, Cryofracture Tool Set for M-23 Mines (sheets 1 through 5)] was modified to cryofracture the test munitions. The mine drum tooling uses a lower tooling tilt table to discharge debris following the cryofracture. A hook, mounted on the upper tooling, engages the tilt table near the bottom of the press stroke and raises the tilt table to approximately 55 deg as the press slide is raised. When the tilt table reaches approximately 55 deg, the hook disengages and the tilt table falls back to its normal position. The mine drum tooling was modified as follows:

- The cutter blades were removed from the existing upper tooling platen
- A new upper tooling platen (drawing 210002, Upper Insert, Mine Drum Tooling) with a flat surface and a new hook mount was fabricated and installed under the old upper tooling platen
- Stop blocks were welded to the hook to replace the upper tooling side skirts which were not used
- The tilt table was machined to provide a flat surface
- Press slide stop blocks with spacer plates (drawing 210003, Slide Stop Block, DPG Press) to accurately calibrate press closure spacing were fabricated and installed on the lower ECC ring

Figures 10 and 11 show the upper and lower tooling mounted in the press, respectively. Figure 12 shows the tilt table just prior to release of the hook.

Munitions Handling Baskets

Three sizes of disposable handling baskets were used to transport the munitions into the cryobath and then from the cryobath to the press tooling. The type I basket was designed to carry up to three M42/M46/M77 grenades, or up to two M61, M67, or M69 hand grenades (drawing 210009, Grenade Handling Basket - Type 1 and fig. 13). The type II basket was designed to carry up to 28 M42/M46/ M77 grenades, or up to 16 M67 or M69 hand grenades, or up to 15 M61 hand grenades (drawing 210010, Grenade Handling Basket - type 2 and fig. 14). The type III basket was designed to carry up to 45 M42/M46/ M77 grenades, or up to 30 M67 or M69 hand grenades, or up to 28 M61 hand grenades (drawing 210011, Grenadge Handling Basket - Type 3 and fig. 15). (Note: During cryofracture testing of inert M42/M46 grenades, it was found that the type III basket tended to warp while being handled by the robot. It was decided to add stiffeners to this type basket to reduce the warpage and to use this basket type only for M42M46/M77 grenades.) The baskets were fabricated from sheet metal with soldered seams. Holes were drilled in the baskets when it was not necessary to hold liquid nitrogen.

Robot Grippers

Two types of robot grippers were used to pick up the munitions handling baskets. Both grippers had the same hook shape but had different hook widths. The narrow gripper (drawing 210001, MTR End Effector Arm and fig. 16) was used to pick up munitions handling basket types I and II. The wide gripper (fig. 17) was used to pick up munitions handling basket type III.

TEST RESULTS

M42/M46/M77 Grenades

A series of 30 cryofractures of inert M42/M46 grenades were performed to establish the parameters to be used in subsequent live grenade cryofractures. The results of these inert tests showed that good brittle fractures and explosive accessing could be obtained with minimal disturbance of the grenade fuzes, short cool-down time, reasonable margin of out-of cryobath warm-up time prior to fracture, reasonable packing for multiple grenade fractures, and the ability of the press to cryofracture up to 45 grenades in a single fracture.

A total of 26 cryofractures of live M77 grenades were performed in two series of tests. The first series of 16 cryofractures (423 grenades total) was performed to demonstrate that a large number of grenades could be cryocooled, robotically handled, and cryofractured with good explosive accessing and no explosions during the fracture process. A total of 423 grenades were cryofractured with no explosions in the press. A single grenade exploded in the open grate furnace during early tests. After adjustment of the press closure spacing (crush height) and grenade spacing on the press tooling, the remaining 352 grenades were cryofractured and burned in the open grate furnace with no explosions. A second series of 10 cryofractures (10 grenades total) was performed to determine the press closure spacing limits necessary to avoid explosions during the fracture. It was determined that the M77 grenade will not explode during the fracture if the press closure spacing (crush height) is 0.75 in. or greater.

Inert M42/M46 Grenade Testing

Table 5 summarizes the testing of inert M42/M46 grenades. A total of 267 grenades were cryofractured in a series of 30 tests. For tests 1 through 26, the number and location of the grenade type (i.e., M42 or M46) were recorded to allow identification of differences in the fracture characteristics of the two types. This practice was abandoned after test 26 because no differences were observed. Tests 1 through 26 used manual operations to place the munitions handling baskets in the cryobath, remove the baskets from the cryobath, and place the baskets on the press tooling. Tests 27 through 30 used the robot to perform munition basket handling operations. Tests 1 thorugh 4 investigated

the effects of press closure spacing on the ability of the press tooling to provide good accessing of the main explosive charge while minimizing undue force on the fuze elements. Test 1 used a press closure spacing of 1.375 in., a spacing that is approximately 0.125 in. less than the diameter of the M42/M46 grenades. Figure 18 shows the condition of the grenades after the cryofracture. Excellent brittle fracture and explosive accessing was obtained with no evidence of detonator crushing. Very similar results were obtained in tests 2 through 4, which used smaller press closure spacings, i.e., greater crushing of the grenades (figs. 19 through 21, respectively). After test 4, a press closure spacing of 1.25 in. was selected for all subsequent M42/M46/M77 grenade cryofractures. Two additional cryofractures, tests 5 and 6, were performed at the selected closure spacing to verify repeatability of results (figs. 22 and 23, respectively).

Tests 1 through 6 used munitions handling baskets that immersed the grenades in approximately 1.25 in. of liquid nitrogen while being transported from the cryobath to the press tooling and while awaiting fracture. Tests 7 through 9 investigated the need for this liquid nitrogen carry-over capability. It was recognized that, if good brittle fractures could be obtained without carrying liquid nitrogen in the baskets, then future baskets could be greatly simplified. The results of tests 7 through 9 (figs. 24 through 26, respectively) showed no observable differences in the fracture characteristics and it was decided that the baskets for all subsequent M42/M46/M77 grenade tests would be modified to allow draining of the liquid nitrogen when the basket is removed from the cryobath.

Tests 1 through 9 used a 20 min munition cool-down time, a duration believed to be more than adequate to provide cooling of the munition metal parts to cryogenic temperature, thus removing cool-down duration effects from the press closure spacing and liquid nitrogen carry-over test results. Tests 10 through 12 investigated the effects of reduced grenade cool-down time. Tests 10 through 12 used cool-down times of 10, 8, and 6 min., respectively. No evidence of ductility or any other differences in fracture characteristics were observed in the debris from tests 10 through 12 (figs. 27 through 29, respectively). After test 12, a cool-down time of 10 min. was selected for all subsequent M42/M46/M77 grenade cryofractures. It was recognized, however, that if it was desirable to minimize cool-down duration, shorter duration's could be used. Tests 13 and 14 were performed at the selected cool-down time to verify repeatability of results (figs. 30 and 31).

Following test 14, a general review of the results of all previous tests was performed and it was observed that, of those tests conducted with 1.25 in. press closure spacing, eight of the 33 grenades had fracture lines that passed through the detonator area. It was decided to increase the press closure spacing to 1.375 in. in the belief that less closure spacing would result in less disturbance in the detonator area. (Subsequent tests showed that the greater closure spacing had no effect on the frequency of fractures with fracture lines into the detonator area.)

Tests 15 through 17 investigated the effects of longer out-of-cryobath grenade warm-up times prior to fracture in the press. Normal warm-up time (the time required for the robot to move the munitions handling basket from the cryobath to the press tooling, for

the robot to return to its "home" position between the press and the cryobath, and for the press to cycle) is approximately 60 sec in the existing test facility. Tests 15 through 17 used warm-up times of 80, 100, and 120 sec, respectively. The results of tests 15 through 17 (figs. 32 through 34, respectively) showed good fracture and explosive accessing characteristics, indicating the flexibility to accommodate short delays in future cryofracture demilitarization facility process operations.

Tests 1 through 17 used 0.5 in. end-to-end spacing between grenades. Tests 18 through 26 investigated the effects of closer grenade spacing in the baskets. Minimizing grenade spacing allows more grenades to be fractured in a fixed size basket. Tests 18 through 22 maintained the 0.5 in. end-to-end spacing while varying the side-to-side spacing from 1.0 to 0 in. Tests 18 through 22 results showed that good fracture and explosive accessing characteristics could be obtained with zero side-to-side grenade spacing (figs. 35 through 39, respectively). It was decided to use zero side-to-side grenade spacing for all subsequent tests. Tests 23 and 24 investigated the effects of reduced end-to-end spacing with zero side-to-side spacing. Test 23 simulated an end-to-end spacing consistent with full nesting of grenades containing safety pins. Test 24 used full end-to-end nesting of grenades without safety pins. The results of tests 23 (fig. 40) and 24 (figs. 41 and 42) showed good fracture and explosive accessing characteristics. It was decided, however, that in order to minimize the possibility of stressing the grenade detonators during the fracture, a 0.5 in. end-to-end spacing would be used for all subsequent fractures. Tests 25 and 26 verified repeatability of results for the selected grenade spacing (figs. 43 and 44, respectively). Tests 27 through 29 investigated the cryofracture of 45 M42/M46 grenades in a single press cycle (figs. 45 through 47, respectively). For these tests, the press was operated remotely by the computer control system in order to obtain an accurate measurement of the peak fracture load. The measured fracture loads were 310, 342, and 345 tons for tests 27 through 29, respectively. Test 30 investigated the effects of application of the full press capacity, 500 tons, to fully crush the grenades. The debris from this test was crushed to a thickness of 0.5 in. (fig. 48).

Live M77 Grenade Testing

Table 6 summarizes the testing of live M77 grenades. A series of 26 tests, with two different goals, was conducted. Tests 1 through 15 and 26 were performed to demonstrate that a large number of grenades could be cryocooled, robotically handled, and cryofractured with good explosive accessing and no explosions during the fracture process. Tests 16 through 25 were performed to determine the press closure spacing limits necessary to avoid explosions during the fracture. An explosion during fracture was not an unexpected event for tests 16 through 25.

The debris from all tests was burned in the open grate furnace which was operated with an average below-grate temperature in the range of 1,500-1,700°F. When burned, the functioning of the grenade detonators could be heard from the control center and seen (as flashes) on the CCTV monitor. For tests 1 through 10, 16 through 18, and 24,

the press tooling tilt table hook was initially disabled to permit the cryofractured debris to be examined and photographed before removal from the lower tooling. Tests 1 to 3 cryofractured a single grenade. Figures 49 and 50 show the debris from test 1 on the press tooling following the fracture. Figure 50 shows the characteristic cracks in the grenade body at the 6 and 12 o'clock positions. Figure 50 shows the cracks in the fuze-end of the grenade with the explosive clearly visible. Figure 51 shows the debris from test 1 after dumping into the fragment cart below the press. The grenade body, fuze-end, and copper cone are seen to be in separate pieces. The explosive was completely separated from the grenade body pieces and dispersed in many small pieces, most of which was the size of table salt or less. It was theorized that the Comp A-5 is crystallized by the cryocooling process. Figures 52 and 53 show the debris from test 2 on the press tooling and in the fragment cart, respectively. Figures 54 and 55 show the debris from test 3 on the press tooling and in the fragment cart, respectively. For tests 2 and 3, the fuze-end of the grenade remained attached to half of the body.

Tests 4 through 8 cryofractured an increasing number of grenades, up to a maximum of 45 (the capacity of the largest munitions handling basket). Figure 56 shows the debris from test 4 on the press tooling. Figures 57 and 58 show the debris from test 4 in the fragment cart. Figures 59 and 60 show the debris from test 5 on the press tooling and in the fragment cart, respectively. Examination of the cryofractured grenades on the press tooling following test 6 (figs. 61 and 62) revealed that, while the grenades were accessed, the degree of accessing was less than seen in previous tests. Figure 63 shows the debris from test 6 in the fragment cart. Two of the grenades were not broken up into pieces. Test 6 debris recovered from the open grate furnace is shown in figure 64. One grenade is seen to contain cracks which permitted the explosive to burn but the grenade body remained essentially intact. It was decided to reduce the press closure spacing from 1.312 to 1.25 in. for subsequent tests. Figures 65 and 66 show the debris from test 7 on the press tooling. Improved grenade accessing was observed, however, examination of the cryofractured debris from test 8 (figs. 67 and 68) again revealed that, for some grenades, particularly those located in the center area of the array, the accessing was less than desired. When the debris from test 8 was dumped into the open grate furnace, one grenade exploded approximately 2 min. after entering the furnace, clearly indicating that adequate accessing was not achieved. Damage from the explosion was limited to the furnace grate and at least one small tear in the building sheet metal siding. The furnace grate was already in poor condition and was scheduled for replacement. Test 8 debris was recovered from the furnace grate and from the surrounding area where it had been blown out of the furnace. Nine of the recovered grenades were not adequately broken apart by the cryofracture. It was theorized that the confinement produced by the use of zero side-to-side grenade spacing limited grenade accessing. It was decided to increase the side-to-side grenade spacing to approximately 0.25 in. for test 9. Figure 69 shows the grenades in the munitions handling basket for test 9. The wood strips used to position the grenades with the desired spacing can be seen. Examination of the cryofractured grenades on the

tooling following test 9 (fig. 70) showed greatly improved grenade accessing. After test 9, the order of the tests was changed to first conduct tests 16 through 25 to determine the press closure spacing limits necessary to avoid explosions during the fracture. [Note: the test numbers are consistent with those shown in the Test Plan (ref 1)].

Test 16 was the application of the full press tonnage (approximately 560 tons) to a single M77 grenade with no closure spacing limits. An inert M42 grenade was first crushed to determine that the full tonnage crush height was approximately 0.25 in. The press bottom-of-stroke limit switch was then set at 0.25 in. Test 16 produced a not unexpected explosion during the fracture. The press tonnage was 96 tons (much less than the full press capacity), indicating that the explosion occurred before the closure spacing reached 0.25 in. Figure 71 shows the debris remaining on the press tooling after the fracture and explosion. Other than a single small gouge in the lower tooling, no damage to the tooling or any other equipment was observed.

Test 17 was a repeat of test 16, but with the press closure spacing set to a minimum of 0.5 in. This test also produced an explosion during the fracture. The explosion appeared to occur near the bottom of the press stroke, i.e., near a closure spacing of 0.5 in. The press tonnage was 75 tons. Nearly all of the debris from the grenade was blown off the tooling by the explosion. Examination of the lower tooling revealed a small, approximately 0.125 in. deep depression in the surface of the tilt table. It is believed that this depression was produced by application of the full press tonnage to the inert grenade prior to test 16. The depression was not seen following test 16 because it was hidden by the munitions handling basket. It was decided that subsequent tests would avoid placing test munitions in the area of the depression.

Tests 18 through 25 were performed with one inert M42 grenade and one live M77 grenade in order to provide balanced handling basket loading while avoiding the placement of the live grenade in the area of the tooling depression. Test 18 was a repeat of test 17, but with the press closure spacing set to a minimum of 0.75 in. No explosion occurred during the fracture. Figure 72 shows the debris on the press tooling after the fracture. Tests 19 through 25 were repetitions of test 18 with no explosions occurring during these fractures. Figure 73 shows the debris from test 24.

Based on the results of tests 18 through 25, it was concluded that the press closure spacing of 1.25 in. used in test 9 provided significant margin to avoid explosions during grenade cryofracture. The press closure spacing for test 10 was, therefore, reduced to 1.18 in. to provide greater explosive accessing. Figure 74 shows the debris on the press tooling following test 10. Good explosive accessing was obtained for all grenades.

Tests 11 through 14 and 26 used the same test conditions as test 10. For all of these tests, an inert M42 grenade was placed in the center of the array to avoid placement of a live M77 grenade in the area of the tooling depression. Test 26 was not planned, but was added to complete the processing of all remaining M77 test munitions.

M69/M67 Hand Grenade Testing

A series of 20 cryofractures of inert M69 hand grenades was performed to establish the parameters to be used in subsequent live M67 hand grenade cryofractures. The results of these inert tests showed that good brittle fractures and explosive accessing could be obtained with minimal disturbance of the grenade fuzes, short cool-down time, reasonable margin in out-of cryobath warm-up time prior to fracture, reasonable packing for multiple grenade fractures, and the ability of the press to cryofracture up to 16 hand grenades in a single fracture.

A total of 29 cryofractures of 330 live M67 hand grenades were performed to demonstrate that a large number of grenades could be cryocooled, robotically handled, and cryofractured with good explosive accessing and no explosions during the fracture process.

Inert M69 Hand Grenade Testing

Table 7 summarizes the testing of inert M69 hand grenades. A total of 103 grenades were cryofractured in a series of 20 tests. These tests provided data for subsequent live testing of M67 hand grenades (M69 and M67 hand grenades have the same external geometry). The main explosive cavities of the M69 hand grenades were filled with a plaster material to simulate the explosive. All tests except tests 3 and 7 used the robot to place the munitions handling baskets in the cryobath, remove the baskets from the cryobath, and place the baskets on the press tooling.

The debris from all M69 hand grenade cryofractures exhibited some ductile deformation in the grenade bodies. It was theorized that the relatively thin wall permitted the grenade to deform ductilly until sufficient stress could be applied to effect brittle fracture.

Tests 1 through 6 investigated the effects of press closure spacing on the ability of the press tooling to provide good accessing of the main explosive charge while minimizing undue force on the fuze elements. Test 1 used a press closure spacing of 2.25 in., a spacing that is approximately 0.25 in. less than the diameter of the M69 hand grenade. Figure 75 shows the condition of the grenades after the cryofracture. Excellent explosive accessing was obtained with no evidence of fuze crushing. Very similar results were obtained in tests 2 and 3 which used smaller press closure spacings, i.e., greater crushing of the grenades (figs. 76 and 77, respectively). After test 3, a press closure spacing of 2.0 in. was selected for all subsequent inert M69 and live M67 hand grenade cryofractures. Two additional cryofractures, tests 4 and 5, were performed at the selected closure spacing to verify repeatability of results (figs. 78 and 79, respectively).

Tests 1 through 5 used a 20 min. or greater cool-down time, a duration believed to be more than adequate to provide cooling of the munition metal parts to cryogenic temperature. Tests 6 through 8 used a 10 min. cool-down time and also investigated the need to immerse the grenades in liquid nitrogen while being transported from the cryobath

to the press tooling and while awaiting fracture. It was recognized that, if good brittle fractures could be obtained without carrying liquid nitrogen in the baskets, then future baskets could be greatly simplified. The results of tests 6 through 8 (figs. 80 through 82, respectively) showed no observable differences in the fracture characteristics and it was decided that the baskets for all subsequent inert M69 and live M67 hand grenade tests would be modified to allow draining of the liquid nitrogen when the basket is removed from the cryobath. Tests 9 and 10 investigated the effects of further reductions in cool-down time. Test 9 used a cool-down time of 8 min. and test 10 used a cool-down time of 6 min. No differences in fracture characteristics were observed in the debris from tests 9 and 10 (figs. 83 and 84, respectively). After test 10, a cool-down time of 10 min. was selected for all subsequent inert M69 and live M67 hand grenade cryofractures. It was recognized, however, that if it was desirable to minimize cool-down duration, shorter durations could be used. Test 11 was performed at the selected cool-down time to verify repeatability of results (fig. 85).

Tests 12 through 14 investigated the effects of longer out-of-cryobath grenade warm-up times prior to fracture in the press. Normal warm-up time (the time required for the robot to move the munitions handling basket from the cryobath to the press tooling, for the robot to return to its "home" position between the press and the cryobath, and for the press to cycle) is approximately 60 sec. Tests 12 through 14 used warm-up times of 80, 100, and 120 sec., respectively. The results of tests 12 through 14 (figs. 86 through 88, respectively) showed good fracture and explosive accessing characteristics, indicating the flexibility to accommodate short delays in future cryofracture demilitarization facility process operations.

Test 15 investigated the effects of zero grenade spacing in the baskets, i.e., the grenades were in contact end-to-end and side-to-side (fig. 89). Minimizing grenade spacing allows more grenades to be fractured in a fixed size basket. Tests 16 and 17 verified repeatability of results for the zero grenade spacing (figs. 90 and 91, respectively).

Tests 18 through 20 investigated the cryofracture of 16 M69 hand grenades in a single press cycle (figs. 92 through 94, respectively). For these tests, the press was operated remotely by the computer control system in order to obtain an accurate measurement of the peak fracture load. The measured fracture loads were 241, 226, and 263 tons for tests 18 through 20, respectively.

Live M67 Hand Grenade Testing

Table 8 summarizes the testing of live M67 hand grenades. A total of 330 M67 grenades were cryofractured in a series of 29 tests. For tests 1 through 5, 7, and 8, the press tooling tilt table hook was disabled to permit the cryofractured debris to be examined and photographed before removal from the lower tooling. All tests used the press closure spacing (2.0 in.) and cool-down time (10 min.) established during inert M69 hand grenade

tests. Tests 1 through 3 cryofractured a single hand grenade. Tests 4 through 8 cryofractured an increasing number of hand grenades, up to a maximum of 16. Figures 95 through 97 show loaded munitions handling baskets with 2, 3, and 9 M67 grenades, respectively. Test 9 was a special demonstration test for a U.S. Army observer. Tests 10 through 20 were repetitions of test 8. For tests 23 through 28, the number of grenades cryofractured was reduced to 12 in order to remain within the 5 lb per flight limit of an APE 1236 rotary kiln. Test 29 processed the leftover grenades. Tests 8 through 29 used a water flush of the fragment cart prior to dump of the debris into the furnace. This flush was added to suppress the immediate flashing of the explosive after dump into the furnace and to simulate the operation of a production demilitarization process where flushing of the press discharge chute would be desirable to prevent buildup of explosive powder. For Tests 8 through 23, the water flush was added to the fragment cart after the cryofractured debris was removed from the press tooling. For tests 24 through 29, the flush was added to the fragment cart before the debris was removed from the tooling. The latter approach proved more effective in removing powdered explosive from the surfaces of the fragment cart. The quantity of flush water was varied from 1 to 4 gal. per flush. In a production demilitarization facility, the quantity of flush would be the minimum amount required to (1) prevent buildup of explosive material in the flow path from the press discharge chute to the rotary kiln inlet, and (2) prevent immediate flashing of the explosives upon entry to the kiln. For the test facility, 2.5 gal. per flush was judged to be the minimum required to provide reasonable explosive removal from the fragment cart.

While the cryofracture of all 330 M67 hand grenades was performed without explosions, a number of explosive events did occur during open grate furnace burning of the debris. The M67 hand grenade contains three explosive components; the fuze with primer and delay elements, the ignition charge/intermediate charge/igniter elements referred to in this report as the detonator, and the main explosive. Most, if not all of the fuze elements are believed to have exploded during burning. If the fuze was separated from the detonator during the fracture or subsequent drop into the fragment cart, then the fuze explosion was heard as a small pop with little or no disturbance of the surrounding debris. If the fuze remained attached to the detonator, then both exploded simultaneously. The intensity of the explosion of the detonators varied widely. Most detonator explosions were heard as a loud bang, accompanied by a small disturbance of the surrounding debris, with no damage to the furnace grate. Some of these detonator explosions ejected debris from the furnace grate. Prior to test 10, an expanded metal screen was placed over the grate to prevent debris from being ejected from the grate. On tests 18, 19, 21, 22, 25, 27, and 28, the detonator explosions produced varying levels of loud booms, accompanied by significant disturbance of surrounding debris, and in some cases, minor damage to the furnace grate. It is believed that the higher level explosions involved not only the detonator, but also some of the main explosive. All of the detonators did not explode. It is believed that when the detonator was separated from the fuze, the explosive in the detonator was exposed at one end and this allowed some of the detonators to burn out instead of exploding. Unless initiated by the explosion of a detonator, the primary explosive simply burned.

While it is uncertain whether the greater-than-detonator-only explosions that occurred during the tests would also occur if the debris were fed to a rotary kiln (with continuous debris agitation during burning) instead of an open grate furnace (with no debris agitation during burning), it is believed that the observed explosions could be accommodated by a rotary kiln. The furnace grate damage resulting from the observed explosions is a poor indicator of the strength of the explosions because the carbon steel grate material has very little strength at the operating temperatures used in the tests, i.e., 1,500 to 1,700°F.

Figures 98 and 99 show the debris on the press tooling for tests 1 and 2, respectively. Figures 100 and 101 show the debris from test 2 in the fragment cart. The grenade body halves and the bare detonator can be seen.

During test 3, the press did not function properly. The press was set up for a fast approach mode (free fall of the press slide at approximately 360 in./min.) to within 2.4 in. of contact of the upper and lower tooling followed by a pressing mode (approximately 19.5 in./min) to the bottom of stroke limit switch. There was normally an approximately 5 sec delay from the completion of the fast approach mode until start of the pressing mode, while the main cylinder filled with hydraulic fluid. During test 3, the fast approach portion of the stroke was very slow and there was a longer than normal delay before start of the pressing mode. The press did complete its stroke, however, and the grenade fracture was satisfactory. Figures 102 and 103 show the test 3 debris on the press tooling and in the fragment cart, respectively. Excellent breakup of the grenade is seen.

Figures 104 and 105 show the debris on the press tooling from tests 4 and 5, respectively.

During test 7, the press again malfunctioned. The fast approach portion of the stroke was again very slow and, after a very long delay, the pressing mode started, but the slide stopped after contact with the grenades but before reaching the bottom-of-stroke limit switch and before engaging the tilt table hook. The test operator assumed control of the press and the slide was raised. After a 30 min. safety wait, the partially crushed grenades were examined and determined to be insufficiently accessed (fig. 106). The bottom-of-stroke limit switch was adjusted to reduce the crush height by 0.25 in. and with the tilt table hook disabled, the press was again cycled. The press cycled normally and the grenades were again examined to determine if the accessing was improved. Some improvement in accessing was observed, but because of the long warm-up period, the degree of accessing was clearly not adequate to prevent explosions during grenade burning. Following consultation with DPG EOD personnel, the tilt table hook was enabled and the nine grenades were dumped into the fragment cart and then into the open grate furnace. Five explosions occurred between 52 and 136 sec after the grenades entered the open grate furnace. After a 30 min. safety wait, the open grate furnace and surrounding area were examined. Damage was limited to severe deformation of the furnace grate and several small holes in

the grate structure. The grate was in poor condition prior to the explosions and was scheduled for replacement. The holes in the grate structure did not require repair. One unexploded grenade body, without the fuze, was found to have been ejected from the open grate furnace by the explosion(s). This grenade body, which landed in a gravel area approximately 30 ft from the furnace grate, was retrieved by DPG EOD personnel and destroyed elsewhere. A thorough search of the area around the open grate furnace, including the top of the building, was conducted and no other grenades were found.

Prior to resumption of testing, the press was examined to try to identify the cause of its erratic behavior. A number of loose wiring connections were found, and following repair, the press was cycled many times without failure.

Figure 107 shows the debris on the press tooling for test 8. A less expensive munitions handling basket, constructed from expanded metal instead of sheet metal, is seen. The debris from all M67 hand grenade cryofractures exhibited some ductile deformation in the grenade bodies. It was theorized that, as with the M69 hand grenades, the relatively thin wall permitted the grenade to deform ductilly until sufficient stress could be applied to effect brittle fracture.

Live M61 Hand Grenade Testing

A series of 61 cryofracture tests (321 total grenades) of live M61 hand grenades was performed to demonstrate that this munition could be robotically handled, cryocooled, and cryofractured without explosions. Since no inert M61 hand grenades were available for testing, these live grenade tests included those tests necessary to establish press closure spacing, cool-down time, the need to immerse the grenades in liquid nitrogen while being transported from the cryobath to the press tooling and while awaiting fracture, minimum allowable grenade spacing in the baskets, and the maximum quantity of grenades that could be fractured in a single press stroke. It was recognized that, for those tests where the fracture parameters were being varied in order to select optimum values, explosions could occur during the fracture and that--if explosions did occur--they did not necessarily indicate failure of the process, but instead indicated that the test parameters were not adequate.

Table 9 summarizes the results of the M61 hand grenade tests. For many tests, the press tooling tilt table hook was disabled to permit the cryofractured debris to be examined and photographed before removal from the lower tooling. After the debris was examined and photographed, the hook was enabled and the press was again remotely cycled to dump the debris into the fragment cart.

Many tests used a water flush of the fragment cart prior to dump of the debris into the furnace. This flush was added to (1) improve the discharge of powdered explosive from the fragment cart, (2) suppress the immediate flashing of the explosive after dump into the

furnace, and (3) simulate the operation of a production demilitarization process where flushing of the press discharge chute would be necessary to prevent buildup of explosive powder. For some tests, the water flush was added to the fragment cart after the cryofractured debris was removed from the press tooling and for other tests, the flush was added to the fragment cart before the debris was removed from the tooling.

Some tests used an additional flush of the fragment cart after the cart was retracted from the furnace in order to remove explosive powder that adhered to the bottom and front lip surfaces. The quantity of flush water was varied from 1 to 2.5 gal. per flush. In a production demilitarization facility, the quantity of flush would be the minimum amount required to (1) prevent buildup of explosive material in the flow path from the press discharge chute to the rotary kiln inlet, and (2) prevent immediate flashing of the explosives upon entry to the kiln.

During the M61 hand grenade tests, many explosions occurred in the open grate furnace while burning the cryofractured debris. On three tests, an explosion occurred in the fragment cart after dumping the cryofractured debris into the open grate furnace, and on three other tests, an explosion occurred in the press tooling during the fracture.

The burning of the cryofractured debris produced one or more explosions of varying magnitude for each grenade. The M61 hand grenade contains three explosive components; the fuze with primer and delay elements, the ignition charge/intermediate charge/igniter elements, referred to in this report as the detonator, and the main explosive. Most, if not all of the fuze elements are believed to have exploded during burning. If the fuze was separated from the detonator during the fracture or subsequent drop into the fragment cart, then the fuze explosion was heard as a small pop with little or no disturbance of the surrounding debris. If the fuze remained attached to the detonator, then both exploded simultaneously. The intensity of the explosion of the detonators varied widely. Most detonator explosions were heard as a loud bang, accompanied by a small disturbance of the surrounding debris with no damage to the furnace grate. Some of these detonator explosions ejected debris from the furnace grate. Prior to test 14, an expanded metal screen was placed over the grate to prevent debris from being ejected from the grate. On many tests, one or more of the detonator explosions produced varying levels of loud booms, accompanied by significant disturbance of surrounding debris and, in some cases, damage to the furnace grate. It is believed that the higher level explosions involved not only the detonator, but also some quantity of the main explosive.

All of the detonators did not explode. It is believed that when the detonator was separated from the fuze, the explosive in the detonator was exposed at one end and this allowed some of the detonators to burn instead of explode. Unless initiated by the explosion of a detonator, the main explosive simply burned.

It is uncertain whether the greater-than-detonator-only explosions that occurred during the tests would also occur if the debris were fed to a rotary kiln (with continuous debris agitation during burning) instead of an open grate furnace (with no debris agitation during burning).

On tests 27, 29, and 43, an explosion occurred in the fragment cart. The tests 27 and 29 fragment cart explosions occurred while the fragment cart was at the dump-to-furnace position. The explosive debris that remained in the fragment cart following the dump to the furnace was first ignited by the burning debris in the furnace and the fire then produced the explosion. The test 27 fragment cart explosion produced an approximately 12 in. offset rupture of the 0.5 in. thick steel lower lip of the fragment cart. The test 29 fragment cart explosion produced no damage. The test 43 fragment cart explosion occurred after the fragment cart was retracted from the dump-to-furnace position and as the cart approached its home position under the press discharge chute. This explosion again ruptured the lower lip of the fragment cart and also damaged a wood building partition. Figure 108 shows the fragment cart damage from test 27 (on the left) and test 43 (on the right). The damage indicated an explosion strength that may not be acceptable for a rotary kiln, particularly if this level of explosion were to occur frequently.

After test 43, the fragment cart bottom was modified (fig. 109) and subsequent tests demonstrated excellent debris removal.

On tests 46, 57, and 61, an explosion occurred in the press tooling during the fracture. Tests 46 and 57 explosions were very low level and produced no damage or disruption of test operations. The test 61 explosion was significantly stronger with resulting damage to the press tooling, the press honeycomb structure and discharge chute, the fragment cart, and the building rollup door at the fragment cart level.

The test 61 explosion was not expected. Fifty-six M61 grenades had been previously fractured successfully at press closure spacings equal to or less than that used for test 61. While the explosive containment features of the press performed as designed, the test 61 explosion raised the issue of the reliability of the cryofracture process for the demilitarization of M61 hand grenades. The cryofracture process must provide sufficient accessing of the explosives to prevent significant explosions during debris burning, but the accessing forces must not be so great that explosions are produced during the fracture. The test 61 explosion showed that the accessing forces for flat plate crushing to a tooling closure spacing of 1.0 in. could produce an explosion. This event left three approaches available that could still validate the process. The first approach is to increase the press closure spacing, accept less breakup of the grenades, and then determine whether the explosions seen during open grate furnace burning of the cryofractured debris would occur in a rotary

kiln. The second approach would be to use a revised press tooling design that would provide explosive accessing by means other than flat plate crushing. This approach would also require verification testing. The third approach would be to remove the fuzes from the grenade bodies prior to cryofracture.

The grenade bodies, fragmentation coils, and primary explosive would then be burned separately from the non-cryocooled fuzes. It is recommended that the first two approaches be pursued before consideration of the fuze removal approach.

Tests 1 through 5 investigated the effects of press closure spacing on the ability of the press tooling to provide good accessing of the main explosive charge while minimizing undue force on the fuze elements. Test 1 used a press closure spacing of 1.7 in. (Note: The Test Plan called for the first test to have a press closure spacing of 2.0 in. This value was reduced due to a concern (based on the M67 grenade test results) that adequate accessing of the thin wall M61 hand grenade would not be achieved at the relatively large 2.0 in. press closure spacing, and that an inadequately accessed grenade would explode in the open grate furnace.) Figures 110 and 111 show the test 1 debris on the press tooling following the fracture and in the fragment cart, respectively. In figure 111, the exposed fragmentation coil is clearly visible along with the explosive inside the coil. The fragmentation coil appeared to be relatively intact, with little deformation, little evidence of brittle fracture, and with only one area where the coil material was broken.

When the grenade debris was dumped into the open grate furnace, the grenade first burned vigorously and then exploded. The furnace grate was slightly bent but no repair was required.

For test 2, the press closure spacing was reduced to 1.46 in. Figure 112 shows improved accessing of the grenade. As in test 1, there was little evidence of brittle fracture of the fragmentation coil. Other than the fuze/detonator, this grenade did not explode when burned in the open grate furnace.

Test 3 was a repeat of test 2 with a 60 min. cool-down time. The fragmentation coils in tests 1 and 2 showed significant ductile deformation. The purpose of test 3 was to eliminate the possibility that the fragmentation coil was not adequately cooled with the 20 min. cool-down time used in tests 1 and 2. Figures 113 and 114 show the debris on the tooling and in the fragment cart, respectively. Again, the fragmentation coil displayed significant ductile deformation. It was concluded that, for the tested press closure spacing, the relatively small cross-section of the fragmentation coil (i.e., 0.090 in. square) allowed it to deform ductilly before sufficient stress could be applied to cause brittle fracture. After test 3, the fragmentation coil material was analyzed and found to be low carbon steel with a cadmium plating.

For test 4, the press closure spacing was reduced to 1.20 in. and the cool-down time was 20 min. Figures 115 and 116 show improved accessing and brittle fracture of the fragmentation coil. When the debris from this test was dumped into the open grate furnace,

the rapid burning of the powderized primary explosive produced a vigorous flame that was immediately (within approximately 1 sec) followed by an explosion. It was concluded that the heat from the rapid burning of the powderized explosive initiated the detonator and a portion of unburned main explosive. The explosion produced no damage. In order to suppress the immediate flashing of the explosive and to simulate the operation of a production demilitarization process where flushing of the press discharge chute would be necessary to prevent buildup of explosive powder, it was decided that--for subsequent tests--a water flush would be added to the debris in the fragment cart before it is dumped into the open grate furnace.

For test 5, the press closure spacing was reduced to 0.95 in. in order to insure that the 1.20 in. closure spacing was well above a spacing that would result in an explosion during the fracture. Figures 117 and 118 show the debris on the tooling and in the fragment cart, respectively. The degree of accessing was somewhat improved over that of test 4. The existing fragment cart flush system was activated for approximately 2 sec, adding approximately 1.0 gal of water to the debris in the fragment cart. No explosion, other than the fuze/detonator, occurred during debris burning. The water flush successfully suppressed the immediate flashing of the powderized main explosive and delayed the explosion of the fuze/detonator after dump into the furnace.

After test 5, a press closure spacing of 1.20 in. was selected for subsequent M61 hand grenade cryofractures. Two additional cryofractures, tests 6 and 7, were performed at the selected closure spacing to verify repeatability of results (figs. 119 through 121). Both tests produced good fracture and debris burn characteristics.

Test 8 investigated the need to immerse the M61 hand grenades in liquid nitrogen while being transported from the cryobath to the press tooling and while awaiting fracture. Figure 122 shows the test 8 debris on the press tooling. One of the two grenades exhibited poor breakup of the outer shell. Figure 123 shows the test 8 grenades in the fragment cart. Both grenades remained essentially in one piece. When dumped into the furnace, both grenades exploded with resulting damage to the furnace grate. It was concluded that, for the 67 sec minimum out-of-cryobath warm-up time provided by the test facility, it was necessary to keep the M61 grenades immersed in liquid nitrogen while being transported from the cryobath to the press tooling and while awaiting fracture. A production demilitarization facility would have the capability to significantly reduce the warm-up time, i.e., to less than 30 sec.

Tests 1, 2, and 4 through 8 used a 20 min. munition cool-down time, a duration believed to be more than adequate to provide cooling of the munition metal parts to cryogenic temperature. Tests 9 through 12 investigated the effects of reduced cool-down time. Figures 124 through 126 show the debris on the press tooling for tests 9 (15 min. cool-down),10 (10 min. cool-down), and 11 (8 min. cool-down), respectively. Good fracture characteristics and debris burning were obtained for all three of these tests. Figure 127 shows the debris on the press tooling for test 12 which had a 6 min. cool-down time. For

this test, less breakup of the grenades was seen. Each grenade remained essentially in one piece when dropped into the fragment cart. When burned in the open grate furnace, each grenade produced an explosion that appeared to involve more than the detonator. One of the explosions damaged the furnace grate. It was concluded that 6 min. cool-down time was not sufficient to provide good breakup during fracture. A 10 min. cool-down time was selected for all subsequent M61 hand grenade cryofractures. The quantity of water flush of the debris in the fragment cart was increased for test 12 to improve removal of explosive powder from the fragment cart.

Tests 13 and 14, were performed at the selected 10 min. cool-down time to verify repeatability of results (figs. 128 and 129, respectively). Both tests produced good fracture and burn characteristics. Prior to test 14, a screen was added to the furnace grate to prevent ejection of debris from the grate. On test 14, the water flush was changed from after the press tooling dump to before the press tooling dump.

Tests 16 through 20 (figs. 130 through 133) investigated the effects of grenade spacing in the baskets. Minimizing grenade spacing allows more grenades to be fractured in a fixed size basket. Tests 21 and 22 (figs. 134 and 135, respectively) verified repeatability of results for the selected grenade spacing.

After test 22, the water flush of the fragment cart was eliminated to prevent freezing of debris in the fragment cart. Tests 23 and 24 each cryofractured 12 grenades. Both of these tests produced larger than detonator only explosions during debris burning. Both tests produced furnace grate damage that required repair. The number of grenades was reduced to 8 or 9 for tests 25 through 31, but larger than detonator only explosions still occurred during debris burning for tests 26, 27, 29, and 30.

Tests 32 through 48 investigated the use of reduced press closure spacing on the cryofracture and debris burning. The goal of these tests was to identify a press closure spacing that would produce better breakup of the grenade fragmentation coils while avoiding explosions during the fracture. Tests 32 through 36 each cryofractured a single M61 grenade at a press closure spacing of 0.94 in. Some improvement in fragmentation coil breakup (relative to the previously selected press closure spacing of 1.20 in.) was seen and greater than detonator only explosions did not occur during debris burning except for test 33 which was not considered representative because the munitions handling basket tipped over when the press slide was lowered and the fracture was not considered typical. (Tipping of the handling basket was generally prevented by preweakening of the handle straps, but this procedure was erroneously omitted for test 33.)

Prior to selecting the 0.94 in. press closure spacing for multiple grenade fractures, tests 37 through 39 were conducted to determine if there was margin in this press closure spacing for explosions during the fracture. Tests 37 through 39 each cryofractured a single

M61 grenade at a press closure spacing of 0.76 in. The debris from these tests (fig. 136) showed a significant improvement in breakup of the fragmentation coils and no larger than detonator only explosions occurred during the debris burning.

Based on the satisfactory results from tests 37 through 39, the nominal press closure spacing was reduced to 0.94 in. for tests 40 through 43. Larger than detonator explosions again occurred during debris burning for tests 41 through 43.

Tests 44 through 46 explored still further reduction in press closure spacing by cryo-fracturing a single M61 grenade at a press closure spacing of 0.62 in. (fig. 137). On test 46, there was evidence that an explosion occurred during the fracture. Debris was ejected from the tooling during the fracture (before the tooling dump) and a strong odor of burned explosive was present in the test building after the test. No smoke was produced and no tooling damage or any other disruption of test operations occurred.

During test 47, the overcurrent breaker on the press main motor was tripped before the press reached the bottom-of-stroke limit switch. The press was restarted and the debris was dumped from the tooling. The press closure spacing applied to the grenades was greater than 0.75 in. but the exact spacing is not known.

For tests 1 through 36 and 40 through 47, press slide stop blocks and the bottom-of-stroke limit switch were used to establish the press closure spacing. The height of the stop blocks was adjusted with shims until the desired closure spacing (verified by crushing and then measuring the thickness of a pipe nipple) was obtained. The bottom-of-stroke limit switch was positioned so that the stop blocks were loaded by the press slide before the limit switch was tripped. This closure spacing technique had the disadvantage that the fracture tonnage was obtained only if it exceed the preload on the stop blocks. On tests 37 through 39, the stop blocks were removed and the bottom-of-stroke limit switch alone was used to establish closure spacing (again verified by crushing and then measuring the thickness of a pipe nipple). The use of these techniques for establishing press closure spacing became suspect during the setup for test 48 when it was discovered that, for a given limit switch position, the press closure spacing varied with fracture load, i.e., the closure spacing was less when a single pipe nipple was crushed than when two pipe nipples were crushed. This phenomena was attributed to the flexibility of the press system, i.e., stretching of the posts and flexibility of the bolster beam and honeycomb structures.

For tests 48 through 61, the press stop blocks were removed and the closure spacing was established by setting the bottom-of-stroke limit switch while applying a measured press load on a known thickness plate positioned on the tooling. For the setup for test 48, the bottom-of-stroke limit switch was positioned to trip when a 436 ton press load was applied to a 0.75 in. thick plate on the tooling. The actual fracture load for test 48 was 344 tons, indicating that the actual press closure spacing was somewhat less than 0.75 in.

The test 48 fracture tonnage of 344 tons for three grenades indicated that the press capacity with the existing main motor would limit the number of grenades that could be fractured to a closure spacing of 0.75 in. to no more than three at-a-time. The existing press, configured to provide a pressing speed of 50 in./min., is limited to approximately 400 tons without overloading the main motor. Installation of a higher power main motor would permit the use of the full 750 ton capacity of the press.

For test 49, the calibrated press closure spacing was increased to 0.88 in. to determine the effect on fracture tonnage. The actual press closure spacing was verified by placing a short length of recoverable copper pipe on the tooling along with the grenades and then measuring the thickness of the crushed specimen after the fracture. The measured fracture tonnage for test 49 was 236 tons, indicating that more than three grenades could be simultaneously fractured in the existing press at a 0.88 in. closure spacing.

For test 50, the calibrated press closure spacing was unchanged and the number of grenades was increased to six. The fracture tonnage was 369 tons, indicating that the press capacity, with the existing main motor, would limit the number of grenades that could be fractured to a closure spacing of 0.88 in. to no more than six at-a-time.

Tests 51 through 53 were performed to determine the minimum press closure spacing that would permit the simultaneous fracture of nine grenades. It was determined that the existing press could fracture nine grenades with a closure spacing of approximately 1.06 in.

The purpose of test 56 was to determine if a reduction in open grate furnace temperature would reduce the explosions that occurred immediately following fragment cart dumping of the debris into the furnace. It was found that reducing the below grate furnace temperature to approximately 1,200°F (from 1,500 to 1,700°F) did not eliminate the explosions.

Test 57 was a repeat of test 56 with an approximately 2.5 gal heated water flush of the fragment cart after the cryofractured debris was dumped from the press tooling. The water was heated to approximately 150°F to prevent icing and retention of debris in the fragment cart. This test produced an explosion on the press tooling during the fracture. This was evidenced by a louder than normal noise during the fracture, ejection of debris from the tooling during the fracture, and the presence of a strong odor of burned explosive in the test building after the test. No smoke was produced. The tooling was not damaged and no disruption of test operations occurred. The fragment cart flush did eliminate the explosion immediately following fragment cart dumping of the debris into the furnace.

Test 58 was a repeat of test 57.

Test 59 was a repeat of test 57 with modified munitions handling basket shoring. The wood quarter rounds that had been used to position the grenades within the handling basket were replaced with wires (fig. 138). The revised handling basket shoring produced no change in the fracture or burn characteristics of the grenades.

Test 60 was a repeat of test 59 with a munitions handling basket modified to allow draining of the liquid nitrogen when the basket was removed from the cryobath. Examination of the cryofractured debris on the press tooling (fig. 139) showed less than desirable breakup of the grenades.

Test 61 was a repeat of test 57 with the final five grenades in the test inventory. This test produced an explosion on the press tooling during the fracture. The explosion occurred as the press reached it's bottom-of-stroke position at a closure spacing of approximately 1 in. The press was E-stopped immediately after the explosion, and because it was time for the ambulance crew to leave for the day, the facility was shut down until the next day. The press was then restarted, the slide was remotely raised, and an inspection of the facility was conducted. The following conditions were observed:

- The press explosion containment chamber successfully prevented damage to the press and the facility equipment in the vicinity of the press.

- The upper and lower press tooling surfaces were indented and pock marked to a depth of approximately 0.15 in. each. The only debris remaining on the tooling was a portion of the grenade handling basket that had to be pried off the lower tooling surface (fig. 140). Four pock marks were located at the grenade fuze-to-body interface for the four peripherally located grenades.

- There was no pock mark for the centrally located grenade. The three indentations (also for peripherally located grenades) were each shaped like a crushed grenade.

- The tooling tilt table hook mounting brackets were broken and the hook had fallen into the fragment cart.

- The press honeycomb structure (designed to absorb explosive loads) was crushed approximately 0.06 in. The press discharge chute attachment bolts (sixteen 0.5 in. bolts) were severed and the discharge chute had dropped approximately 18 in. into the fragment cart. The lower (thin sheet metal) cylindrical portion of the discharge chute was crushed.

- The fragment cart bottom was slightly bent and it's four wheels were broken.

- The cover on the rollup door at the fragment cart level was blown off.

The damaged components were repaired in 4 days. The press honeycomb structure was replaced with a spare unit that was at the test site. The press discharge chute and the fragment cart were repaired. The rollup door was still operable and no repair was required. (The tooling repair was deferred until it is known whether this same tooling will be used for future planned tests with other munitions.)

After the explosion, the video records were reviewed and a number of tests were performed with the press to verify the conditions prior to the explosion. No evidence was found to indicate that the condition of the grenades or the operation of the press were other than planned.

PRODUCTION DEMILITARIZATION FACILITY

The cryofracture tests performed on M42/M46/M77 grenades and M67 hand grenades demonstrated the feasibility of the cryofracture process for demilitarization of these munitions. (The feasibility of the cryofracture process for M61 hand grenades was not clearly established by the current test program, but approaches that may demonstrate this feasibility were identified.) While the Munitions Cryofracture Test Facility is ideal to conduct the development and demonstration tests, it was not designed for rapid throughput rate production demilitarization operations. This section describes (1) design concepts and estimated costs for a production demilitarization facility based on an evolution of the existing test facility, and (2) a discussion of other design concepts with the potential for significant increase in throughput rate.

Production Facility Based on Evolution of Existing Test Facility

Design Basis

The production demilitarization facility design is based on the following groundrules and assumptions:

- The facility will use the existing test facility hydraulic press, portions of press tooling, and press explosive containment chamber components.

- The facility location is not yet decided.

- The facility will use an existing APE-1236 rotary kiln or other thermal treatment process for explosives incineration and metal detoxification.

- The facility will have the capability to process M42/M46/M77 grenades and M67 hand grenades.

- The facility will be sufficiently versatile to accommodate, with minor modifications, the processing of other munitions.

- The facility will provide up to one press fracture per min., which corresponds to up to 60 M42/M46/M77 grenades per min. or up to 49 M67 hand grenades per min. The munitions receiving, unpack, handling, and cryocooling operations will accommodate the press cycle rate.

Facility Design

The existing test facility design requires modification of the following systems in order to provide production demilitarization capability: (1) the front end, i.e., the munitions receiving, unpack, and handling systems, (2) the cryobath, (3) the press tooling, (4) the open grate furnace, which must be replaced with a rotary kiln/afterburner/pollution abatement system, (5) the system that transports the cryofractured debris from the press to the rotary kiln, and (6) the process control system.

Two concepts for increasing the throughput rate of the test facility were identified. Concept 1 (fig. 141) represents the simplest, lowest capital cost approach that could be envisioned. This concept eliminates the use of robots and makes use of a single overhead conveyor and a simple, two axis device for loading the munitions into the press tooling. The main processing building and press location within the building were assumed to be the same as the existing test facility.

Concept 2 (figs. 142 and 143) uses an existing government-owned overhead robot to provide munitions handling. This concept also uses the existing main processing building and press location within the building. Two belt conveyors are used to transport munitions to the main processing building and return empty handling fixtures to the munitions receiving building. This concept provides greater flexibility to accommodate the processing of other munitions and it also provides enhanced personnel and equipment protection features. Figure 144 shows a simplified process flow diagram (PFD) for the concept 2 configuration.

Both concepts require a new, appropriately sized cryobath and both concepts eliminate the use of the existing pedestal robot. This robot is obsolete, its controller will not permit remote recovery, and the manufacturer no longer fully supports the system.

Both concepts require the construction of a munitions receiving building to provide explosion protection for personnel involved in the following activities:

- Unpacking of munitions

- Placement of munitions on handling fixture loading stations

- Attachment of handling fixtures to the munitions
- Transfer of the loaded handling fixtures from the load stations to the input conveyor.
- Control console operation to record munitions input and to control conveyor operation
- Recover munitions handling fixtures from the return conveyor

Multiple handling fixture load stations are provided in order to maintain high throughput rates. The loaded munitions handling fixtures enter the main processing building on an overhead conveyor (concept 1) or a belt conveyor (concept 2) that penetrates the concrete wall of the munitions receiving building. Limit switches are used to stop the input conveyor at known locations.

Concept 1 uses an overhead conveyor to transport loaded munitions handling fixtures from the munitions receiving building, into the main processing building, through the cryobath, and to a location in front of the press. A two-axis press loading machine removes the loaded munition handling fixture from the conveyor and transports it to the press tooling. The munitions are released from the handling fixture onto the tooling and the press loading machine then transports the empty fixture back to the conveyor. The press is then cycled to fracture the munitions.

Concept 2 uses the CIMCORP Model XR-100 overhead robot used at the General Atomics (GA) Pilot Cryofracture Facility and currently stored at Pueblo Army Depot for loading and unloading the cryobath and for loading the press tooling. This robot has sufficient size and capacity to perform all required munitions handling operations. Integration of this robot into the facility would be relatively straightforward. The controller, bridge and mast subassembly, and bridge rails could all be used with little or no modification. A new manipulator arm, capable of reaching into the press tooling, would be required. Figure 145 shows an elevation of the overhead robot in various working positions. The overhead robot picks up each loaded munitions handling fixture from the input conveyor and places it in the cryobath. After the munitions have cooled, the robot removes the handling fixture from the cryobath and transports it to the press tooling. The munitions are released from the handling fixture onto the tooling and the robot transports the empty fixture to the return belt conveyor. The press is then cycled to fracture the munitions.

The existing cryobath must be replaced. The cryobath must be sized to provide the desired throughput rate and the desired munitions cool-down time. The cryobaths (figs. 141 and 142) are sized to provide one cryofracture per minute and a 10 min. cool-down time. It may be desirable to provide larger cryobaths than those (figs. 141 and 142) in order to accommodate unknown munitions that require longer than 10 min. cool-down time.

The existing press tooling must be modified to provide positioning of the munitions on the lower tooling and thus permit use of reusable munitions handling fixtures.

The existing test facility design requires modification of the incineration system in order to provide production demilitarization operations. The existing open grate furnace was not designed for rapid throughput rate operation and it does not contain the necessary effluent cleanup capability. Both production plant concepts replace the open grate furnace with an APE-1236 rotary kiln, an afterburner, and a pollution abatement system. The kiln would be provided with an isolation valve in its feed chute. The APE-1236 rotary kiln is in widespread use at U.S. Army depots for deactivating explosives.

The existing test facility requires modification of the system that transports the cryofractured debris from the press to the rotary kiln in order to provide production demilitarization operations. The existing fragment cart must be replaced with a system that is more appropriately sized and has more rapid operation. Several approaches are possible, depending on the location of the rotary kiln relative to the cryofracture press. Figure 146 shows a debris transfer cart similar in operation to the existing fragment cart. Figure 147 shows a vibratory conveyor that has the potential to reduce or eliminate problems associated with buildup of explosive that may occur in a debris transfer cart. If the cryofracture process can be located in close proximity above an existing rotary kiln, then a direct gravity feed of the debris from the press tooling to the kiln can be used.

The final area of the existing test facility design that requires modification in order to provide production demilitarization operations is the control system. The existing supervisory computer is obsolete and not adequate to control all of the equipment and processes in the modified facility. The primary systems of a production facility, i.e., conveyors, overhead robot, cryobath, hydraulic press, debris transfer cart, and balance of plant systems will be controlled by an integrated process control system. The controls for the existing rotary kiln and pollution abatement system will be independent but integrated into the overall cryofracture facility control system. This is required since the kiln must be capable of independent operation to service other demilitarization needs. Figure 148 shows an interconnecting line diagram for such a system. Figures 149 and 150 show a single line diagram (SLD) and a piping and instrument diagram (P&ID) for the concept 2 configuration, respectively.

The process control system consists of control room equipment, a supervisory computer, a communications interface, local controllers, and a hardwired protection system. The control room equipment consists of computer graphic workstations, operator touchscreens, support terminals, and printers. A conceptual layout of a production plant control room is shown in figure 151. For concept 1, this equipment was assumed to be housed in existing trailers. For concept 2, a new control room building was assumed. The supervisory computer is a Data General MV/5600 or equivalent. The facility uses programmable

logic controllers or imbedded-controllers (instead of the existing blend of relays and direct computer-controlled digital/analog inputs/outputs) to control the process equipment in a real-time closed loop. The supervisory computer sequences and supervises the overall process while the controllers perform the intensive control operations for the process equipment. The existing hardwired protection system is expanded to include additional E-stops for new components and not-to-exceed protection loops to enforce facility safety. Hardwired protection loops are used to enforce flame protection within the rotary kiln, not-to-exceed temperature control for the rotary kiln and pollution abatement system, and a plant trip in the event of draft fan failure. Figure 152 shows the interconnections between the hardwired protection elements.

Facility Throughput

A major goal of the conceptual design was to maximize facility throughput rates to accommodate demilitarization of a large quantity of munitions in a cost-effective manner. The munitions throughput rate of the conceptual production facility is limited by the following:

- The rapidity of munitions unpack and handling fixture loading operations
- The rapidity of the press loading machine (concept 1)
- The rapidity of the overhead robot in performing cryobath loading and unloading and press loading operations (concept 2)
- Press cycle time
- Press tooling size
- Press tonnage capacity
- Debris transfer cart cycle time
- Rotary kiln capacity
- Rotary kiln residence time

The design basis throughput rate of one press fracture per minute requires that one munition loading fixture be loaded and placed on the input conveyor each minute. This can be accomplished by the use of multiple fixture loading stations and the use of several munitions handlers to perform these operations. The relatively short travel distances should make it possible for the press loading machine (concept 1) or the overhead robot (concept 2) to perform their operations within 1 min. The existing press cycle time is 39 sec. A 1 min. cycle time for a debris transfer cart is well within design limits for this type of

device. The rotary kiln can accept a load of cryofractured debris once each minute by using a rotational speed of 1 rpm; a speed within the operating range of the APE-1236 rotary kiln. This rotational speed will provide an 8 min. residence time in the kiln (the use of an 8 min. residence time to destroy all explosive material and detoxify the metal debris must be verified). The APE-1236 rotary kiln has an explosive safety limit of 5 lb of explosive per flight. Table 2 shows key throughput rate limits for the facility.

Alternate Cryofracture Process for Increased Throughput

The throughput rate of a production demilitarization facility based on the use of a large capacity hydraulic press and an APE-1236 rotary kiln is limited. The desirability of significantly increasing processing rate is dependent upon the projected quantity of munitions planned for destruction by the cryofracture process and the time frame required for the destruction. An economic evaluation of any candidate demilitarization process must consider the following factors:

- The quantity of each of the applicable munition types expected to enter the demilitarization stockpile as a function of time
- The projected number of facilities planned to destroy the applicable munitions
- The time allowed to destroy the applicable munitions, i.e., 10 yrs, 20 yrs, etc.

Consideration of these factors leads directly to a plant processing rate required to meet the desired schedule. The above factors were not specified, but if not constrained by the existing test facility, a number of possible high throughput rate demilitarization concepts can be identified.

The primary operations that limit throughput rate for the cryofracture process are the munitions fracture and the debris incineration. The capacity of the munitions fracture operation can be increased by use of (1) multiple processing lines, each with a large capacity hydraulic press; (2) an even larger capacity hydraulic press to fracture a greater number of munitions at once; (3) multiple processing lines with small capacity presses capable of rapid fracture of single munitions; and (4) other approaches using alternate features to fracture the munitions and destroy the explosives.

In addition to GA's effort, a consultant was asked to provide concepts for high throughput rate plants. Dr. Carl Peterson of MIT was consulted. His experience with mining equipment and the U.S. Chemical Weapons Demilitarization Program produced a suggested rotary fracture mill concept that is shown in figure 153. This approach would require development, but it could eliminate the hydraulic press constraint and provide very

rapid throughput rate. The capacity of the debris incineration operation can be increased by using multiple APE-1236 rotary kilns or by using one or more larger capacity rotary kilns.

Effort to investigate means to increase plant throughput rate over that provided by the existing test facility's hydraulic press and a single APE-1236 rotary kiln was limited to identification of these concepts. The feasibility of these concepts can be investigated further when the demil stockpile factors and the Government's plans for development of the cryo-fracture process are specified.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Overall

The cryofracture process is a feasible, safe means for demilitarization of many types of conventional munitions, particularly those munitions that are difficult to handle and disassemble.

The Munitions Cryofracture Test Facility can be used as the basis for a facility for production demilitarization of M42/M46/M77 grenades, M67 hand grenades, and other munitions that are difficult to disassemble. The use of such a facility for demilitarizing M61 hand grenades requires further testing to establish the reliability of the process.

A production demilitarization plant throughput rate would be limited by press capacity and cycle time, or by the capacity of the thermal treatment system for the cryofractured debris. Estimated throughput rate limits are shown in table 2. Use of a larger rotary kiln than the APE-1236, or other thermal treatment system, could significantly increase throughput rate.

The existing hydraulic press has the ability to cycle once per minute when used in conjunction with either a robotic loading system or a pick-and-place machine.

The use of expendable munitions handling baskets is not economic for production demilitarization operations. A conceptual design of a reusable handling fixture has been identified.

An overhead robot could be used for cryobath loading and unloading and press tooling loading operations. The CIMCORP Model XR-100 robot used at the General Atomics Pilot Cryofracture Facility and currently stored at Pueblo Army Depot could be used in a production demilitarization facility.

M42/M46/M77 Grenades

The cryofracture process provides an excellent means for accessing the explosives in these grenades.

A cool-down duration of 6 min. is adequate to provide good brittle fracture

A press closure spacing of 1.18 in. provides good explosive accessing without explosions during the fracture.

Good fractures can be obtained with an out-of-cryobath warm-up duration of up to 2 min.

Good multiple grenade fractures can be obtained with end-to-end spacing of 0.5 in. and side-to-side spacing of 0.25 in.

The existing Munitions Cryofracture Test Facility hydraulic press is capable of fracturing up to approximately 60 grenades at once.

M67 Hand Grenades

The cryofracture process provides an excellent means for accessing the explosives in these grenades.

A cool-down duration of 6 min. is adequate to provide good brittle fracture.

A press closure spacing of 2.0 in. provides good explosive accessing without explosions during the fracture.

Good fractures can be obtained with an out-of-cryobath warm-up duration of up to 2 min.

Good multiple grenade fractures can be obtained with zero end-to-end spacing and zero side-to-side spacing.

The existing Munitions Cryofracture Test Facility hydraulic press is capable of fracturing up to approximately 49 grenades at once.

M61 Hand Grenades

The reliable and consistent performance of the cryofracture process for demilitarization of M61 hand grenades was not clearly established by the test program. The minimum allowable press closure spacing that must be used to avoid explosions during the fracture may not provide sufficient explosive accessing to consistently prevent explosion of the debris in a rotary kiln.

Three approaches that could establish the reliability of the cryofracture process were identified. The first approach is to increase the press closure spacing, accept less breakup of the grenades, and then determine whether the explosions that occurred in the open grate furnace would also occur in a rotary kiln. This approach would have to be demonstrated with a rotary kiln, starting with single grenade cryofractures. The second approach would be to use a revised press tooling design that would provide explosive accessing by means other than flat plate crushing. This approach would also require demonstration. The third approach would be to remove the fuzes from the grenades prior to cryofracture. The grenade bodies, fragmentation coils, and main explosive would then be burned separately from the fuzes.

Recommendations

Select the cryofracture technology as the OB-OD alternative for demilitarization of munitions that are difficult to disassemble.

Construct a production demilitarization facility using Munitions Cryofracture Test Facility equipment where appropriate.

Consider the option of constructing an entirely new cryofracture facility for production demilitarization operations while leaving the Munitions Cryofracture Test Facility in place for future development testing of the cryofracture process for other munitions.

Continue to identify additional munition types that are good candidates for demilitarization by cryofracture. Use the Munitions Cryofracture Test Facility to demonstrate feasibility for new munition types.

Investigate the three identified approaches (rotary kiln burning of grenades cryofractured to greater press closure spacing, redesigned press tooling for improved explosive accessing with less crushing, and removal of the grenade fuzes prior to cryofracture) for establishing cryofracture process reliability for the M61 hand grenade.

For production demilitarization operations, the following facility modifications are recommended:

- Establish the designs for integrating relevant Munitions Cryofracture Test Facility equipment into a selected site, including integration with an existing rotary kiln system or other thermal treatment system.
- Design equipment for the remote unpacking of grenades from 155-mm and 8-in. projectiles.
- Design reusable munitions handling fixtures for each munition configuration to permit the transport, handling, and cryofracture of multiple munitions.

- Fabricate and bench test prototype munitions handling fixtures.
- Use a conveyor to move munitions from an explosively protected receiving/unpacking area into the main processing building.
- If an overhead robot is selected for munitions handling operations, consider use of the CIMCORP Model XR-100 robot used at the General Atomics Pilot Cryofracture Facility and currently stored at Pueblo Army Depot. If this robot is to be used, then design a robot manipulator arm to provide the required motions for handling the munitions handling fixtures.
- Design equipment for transport of cryofractured debris from the press discharge chute to a rotary kiln or other thermal treatment system, including a water flush system to remove explosive debris downstream of the press tooling.
- Upgrade the process control hardware and software.

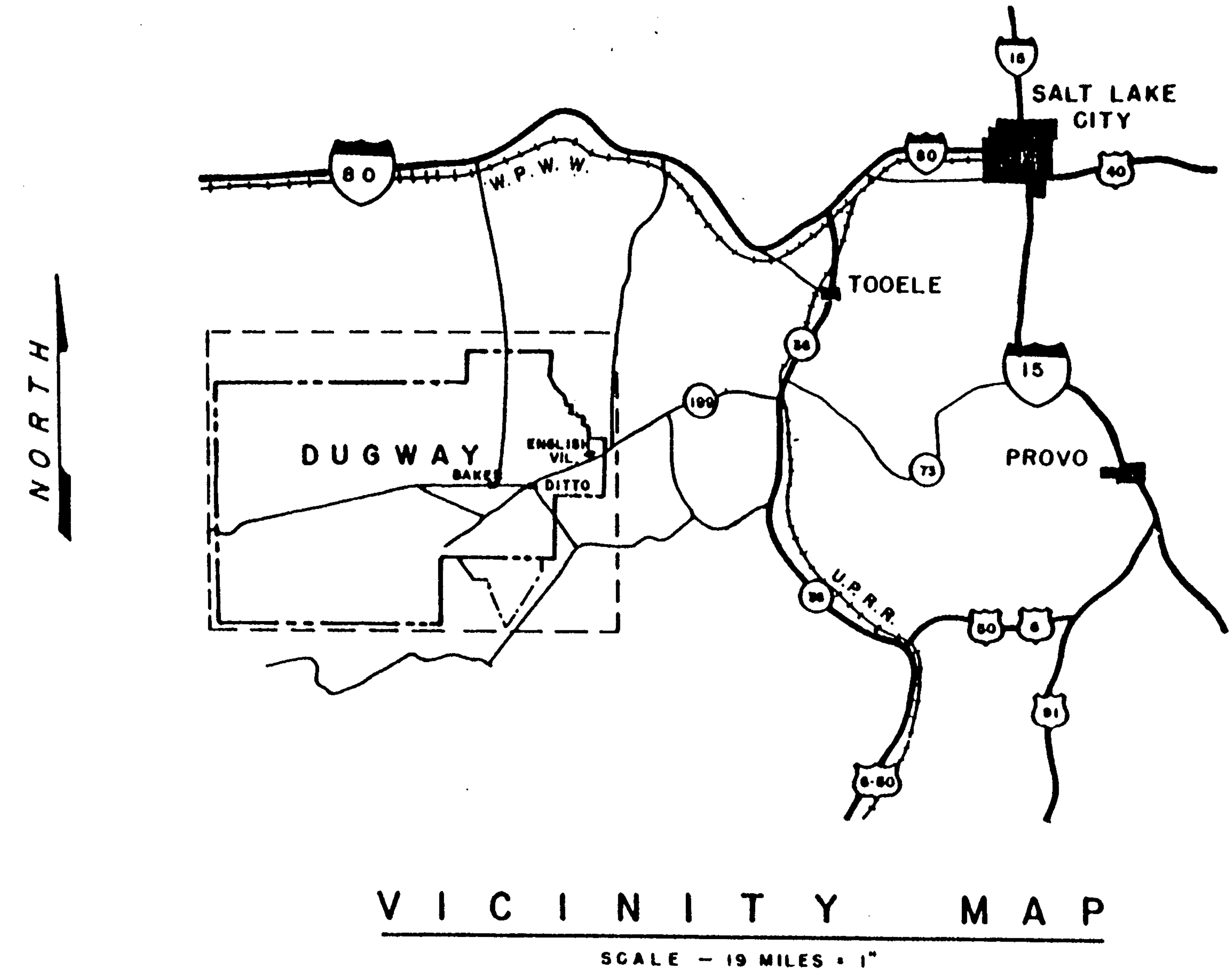


Figure 1
Vicinity map

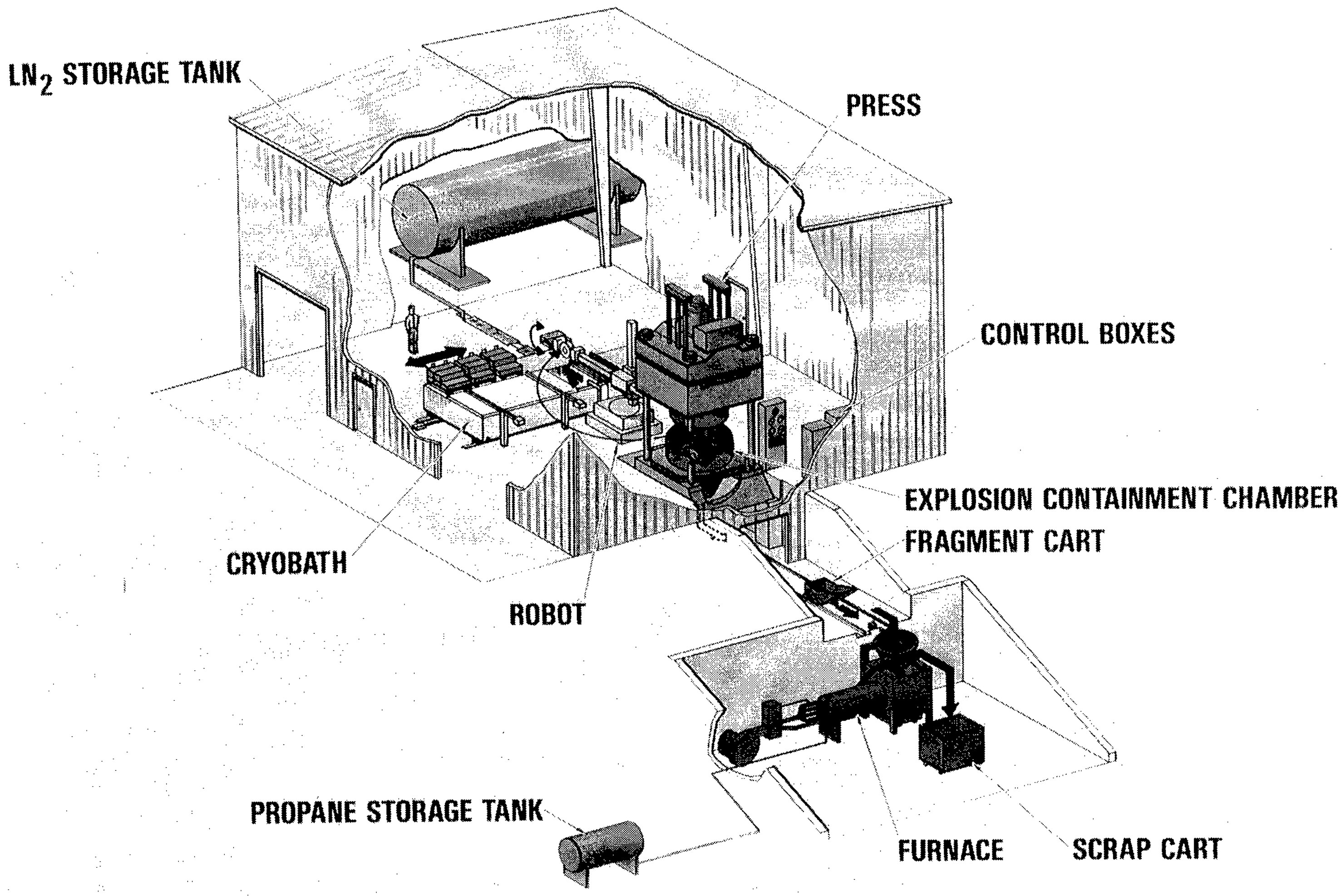


Figure 2
Munitions cryofracture test facility layout

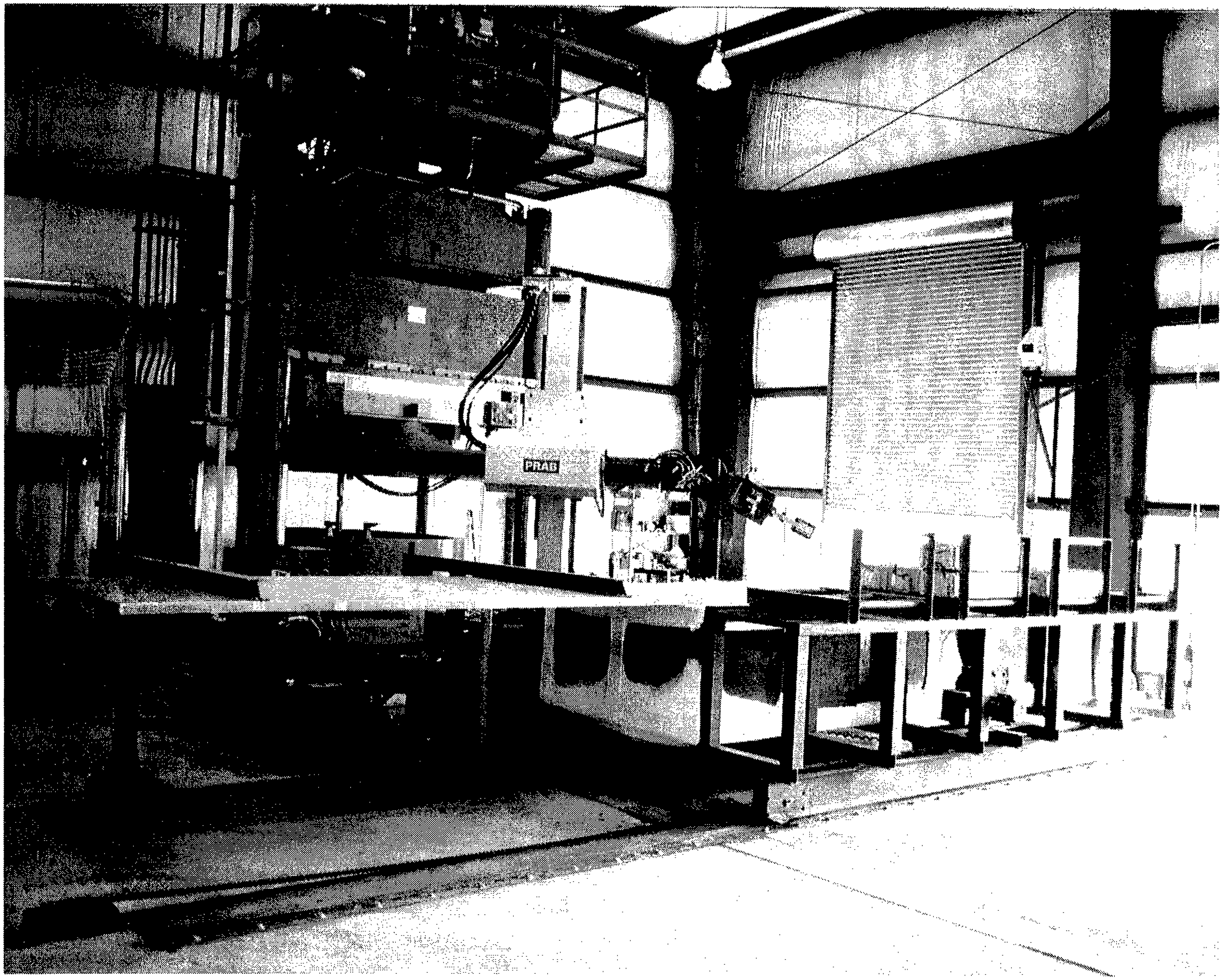


Figure 3
View of press, robot, and cryobath

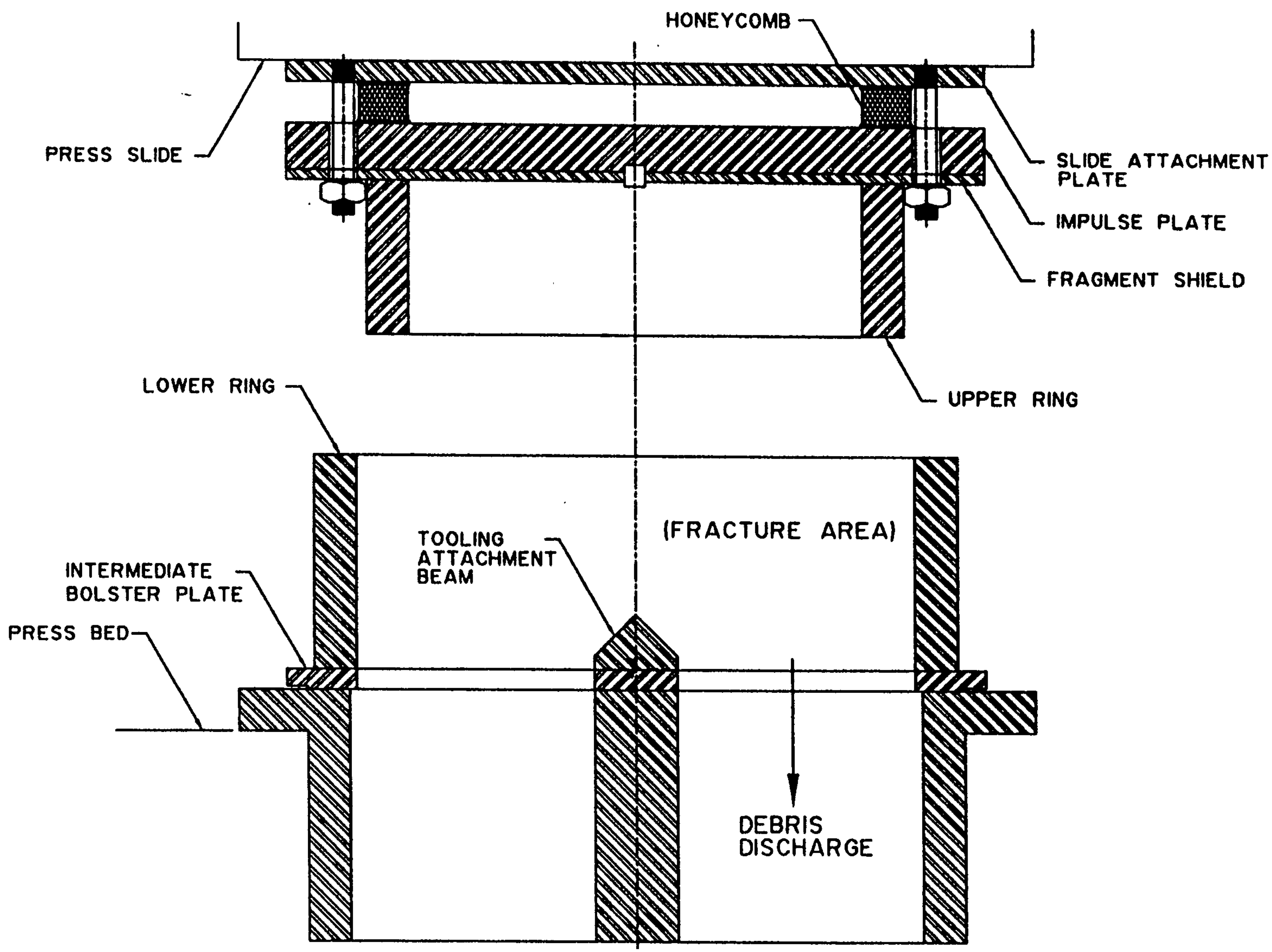


Figure 4
Press ECC components

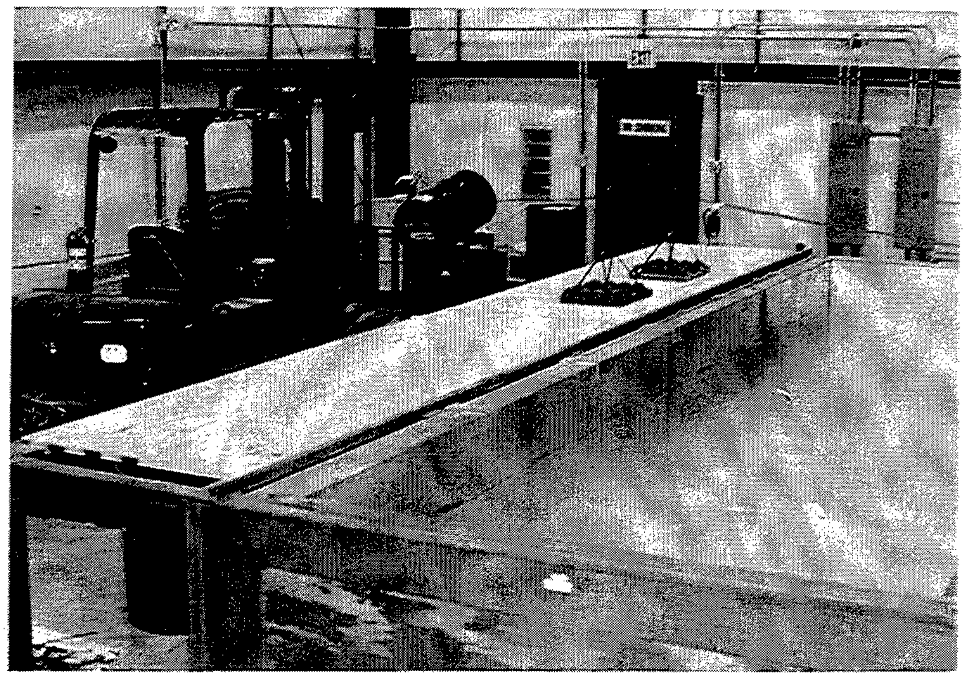


Figure 5
Cryobath loading platform

Figure 6
Fragment cart positioned under press discharge chute

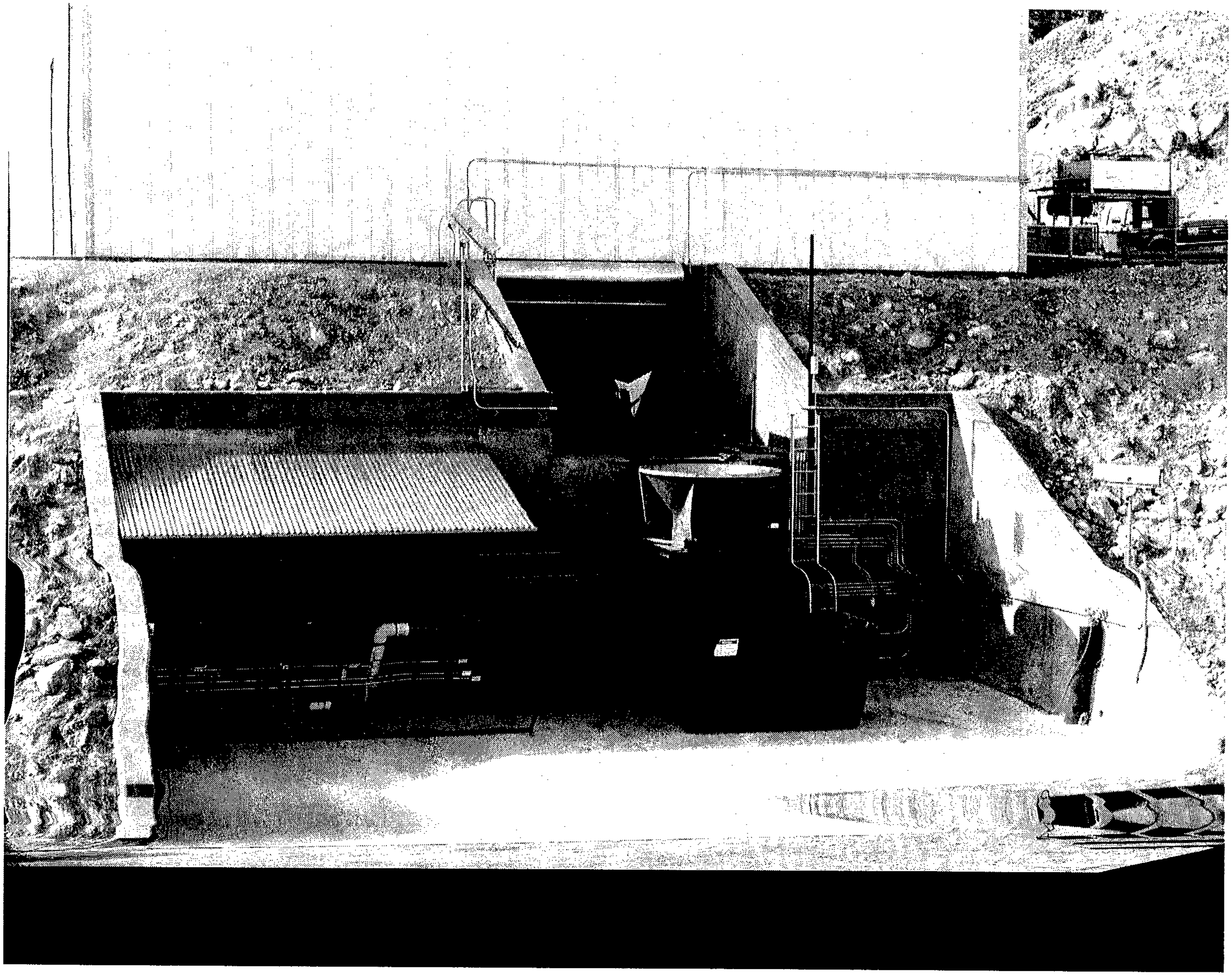


Figure 7
Open grate furnace

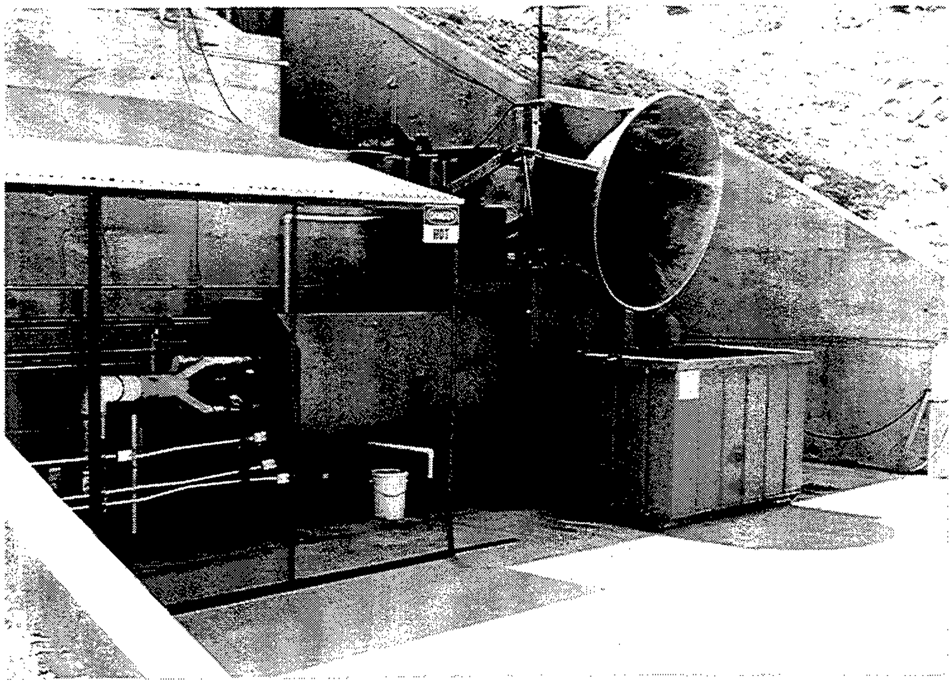


Figure 8
Open grate furnace dump system

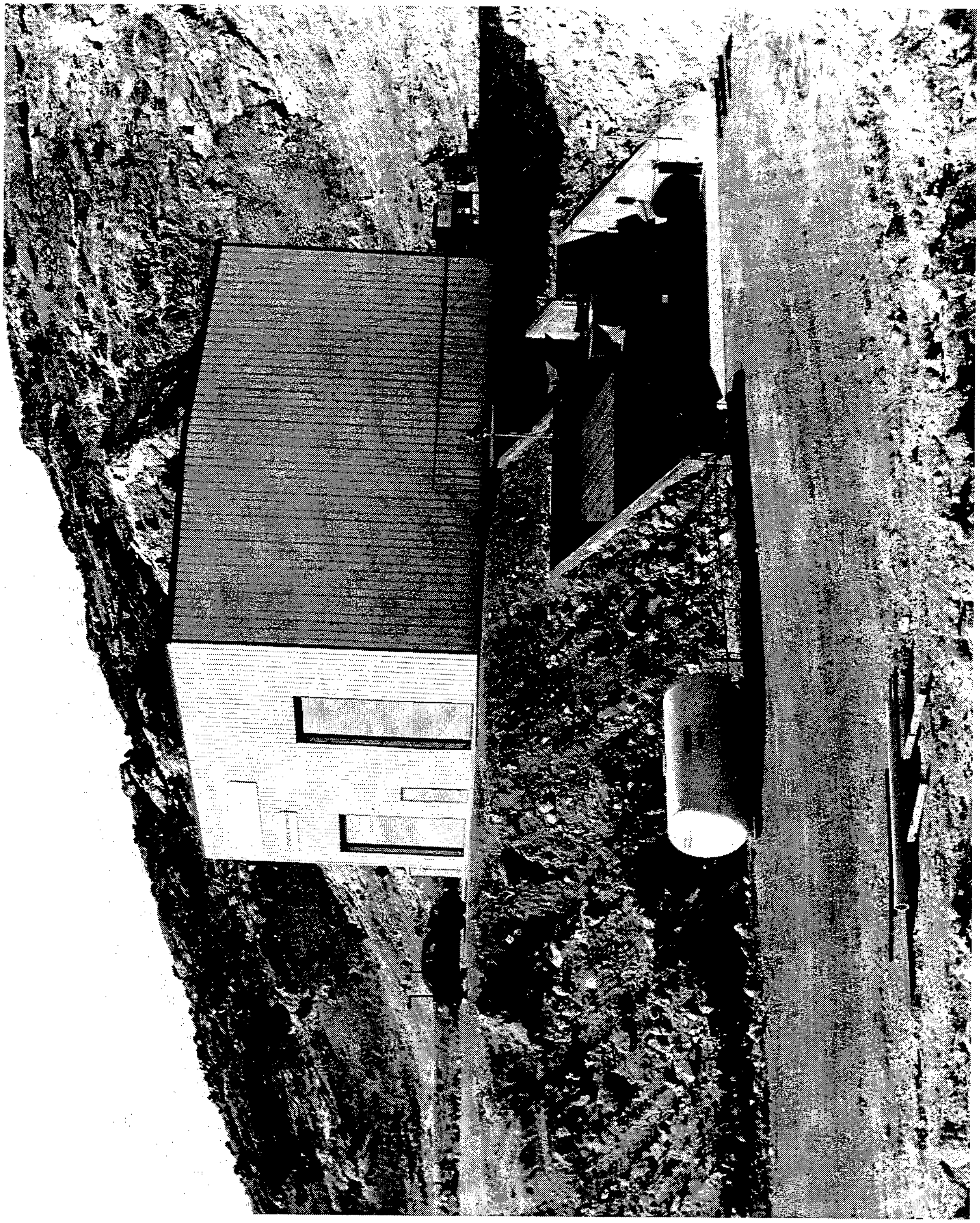


Figure 9
Test facility building

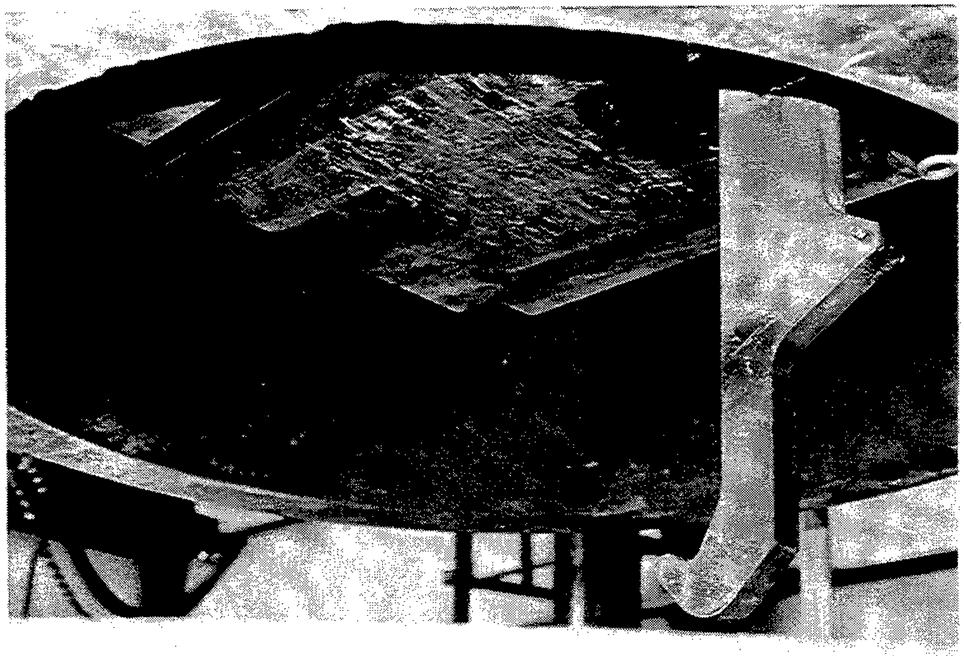


Figure 10
Upper tooling installed in press

Figure 11
Lower tooling installed in press

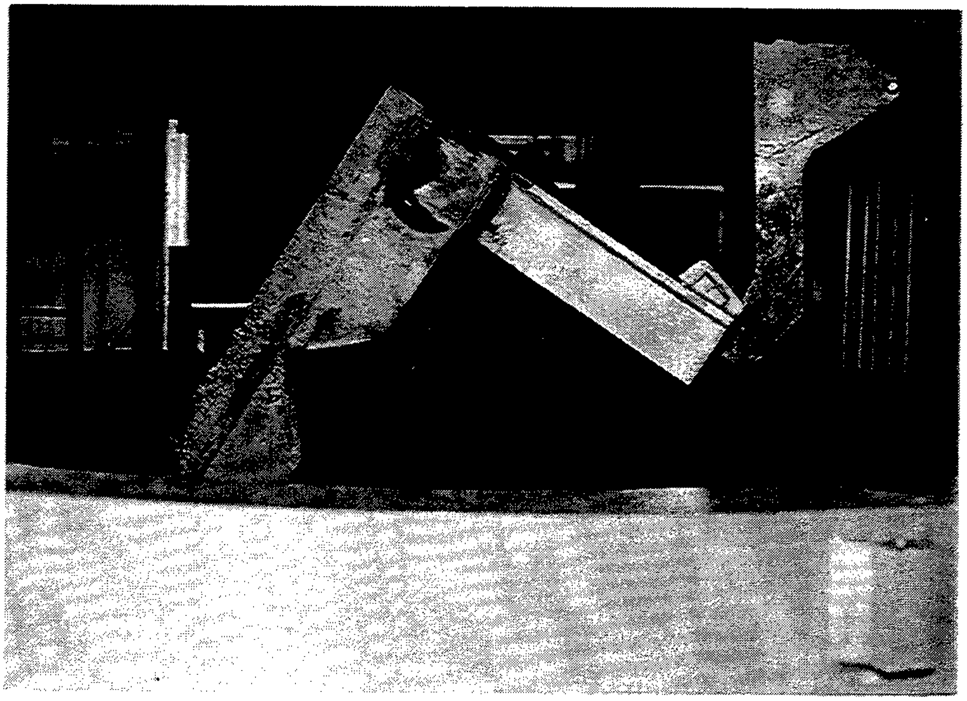


Figure 12
Tilt table just prior to hook release

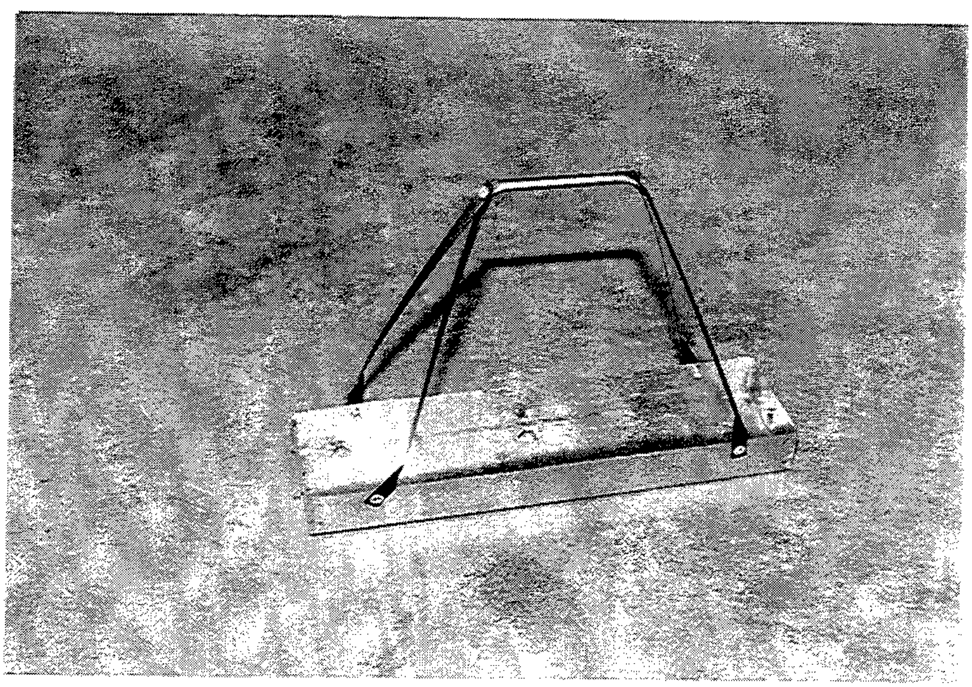


Figure 13
Munitions handling basket type I

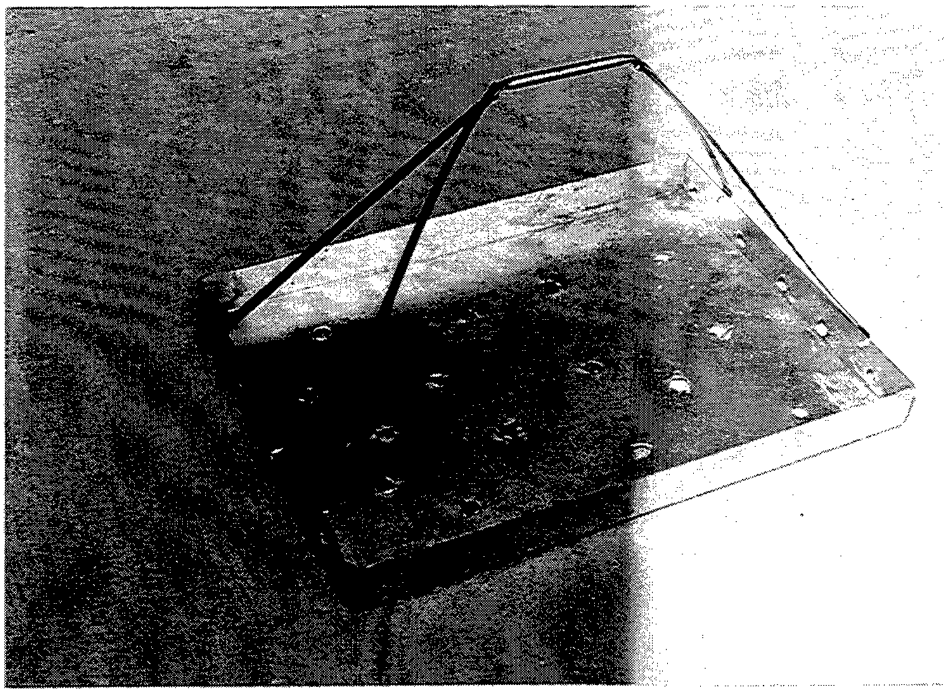


Figure 14
Munitions handling basket type II

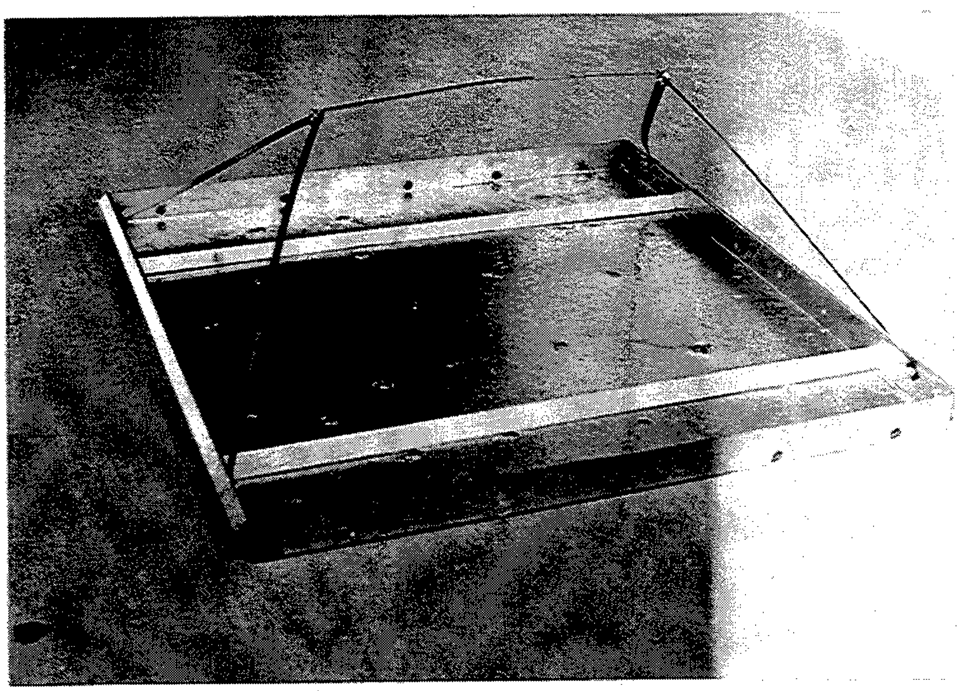


Figure 15
Munitions handling basket type III

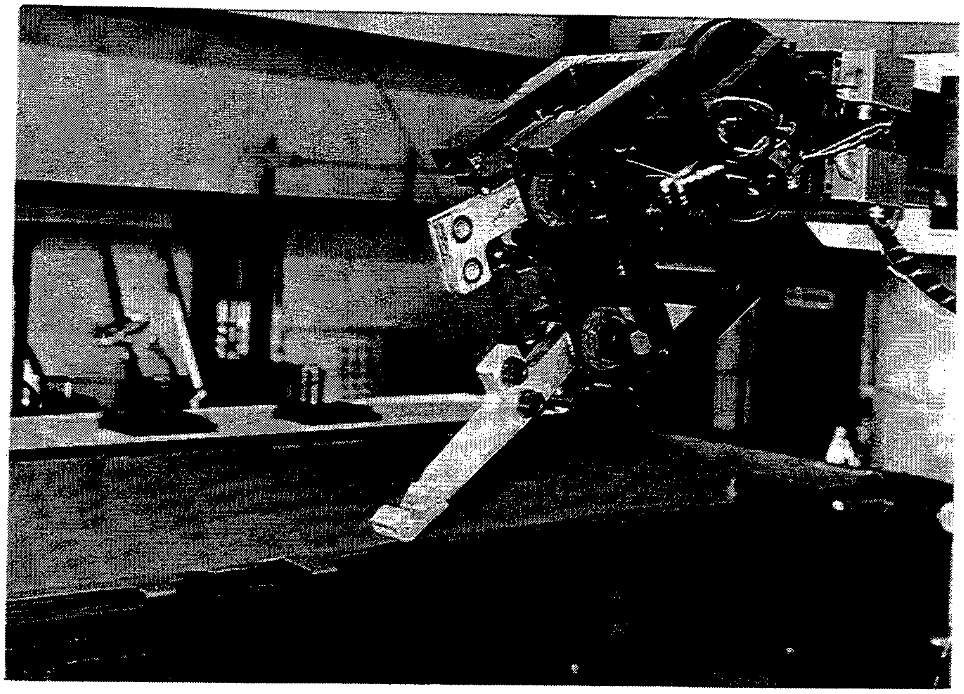


Figure 16
Narrow robot gripper arm

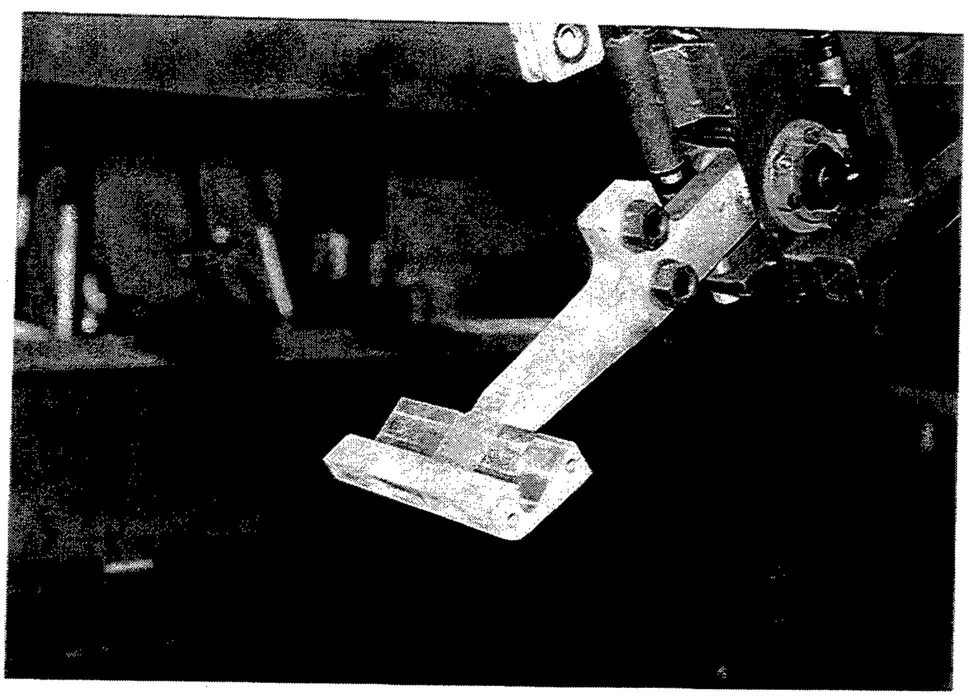


Figure 17
Wide robot gripper arm

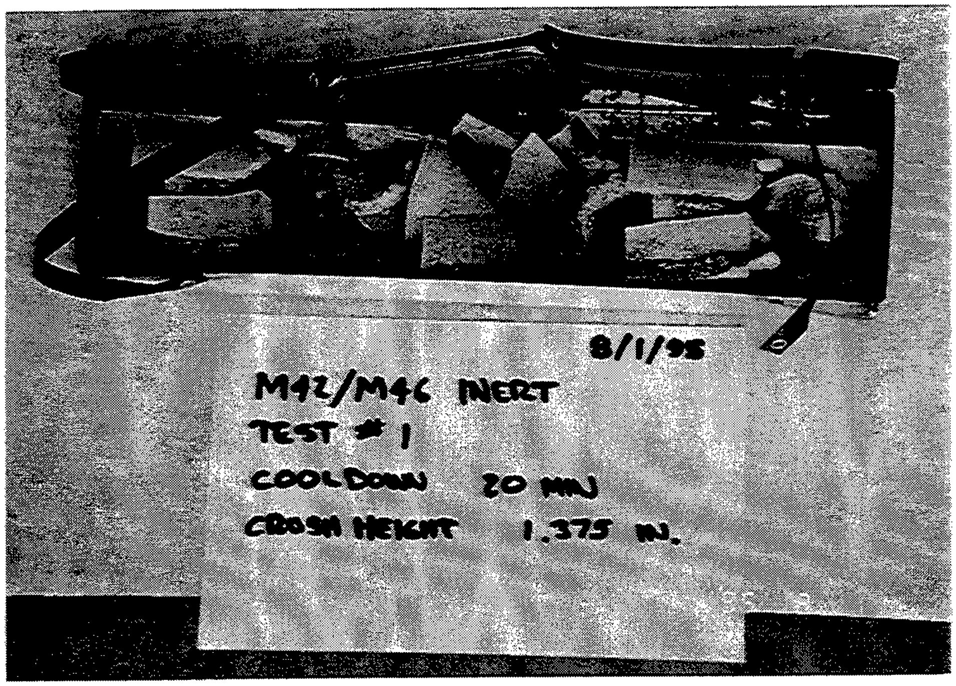


Figure 18
Debris from inert M42/M46 grenade test 1

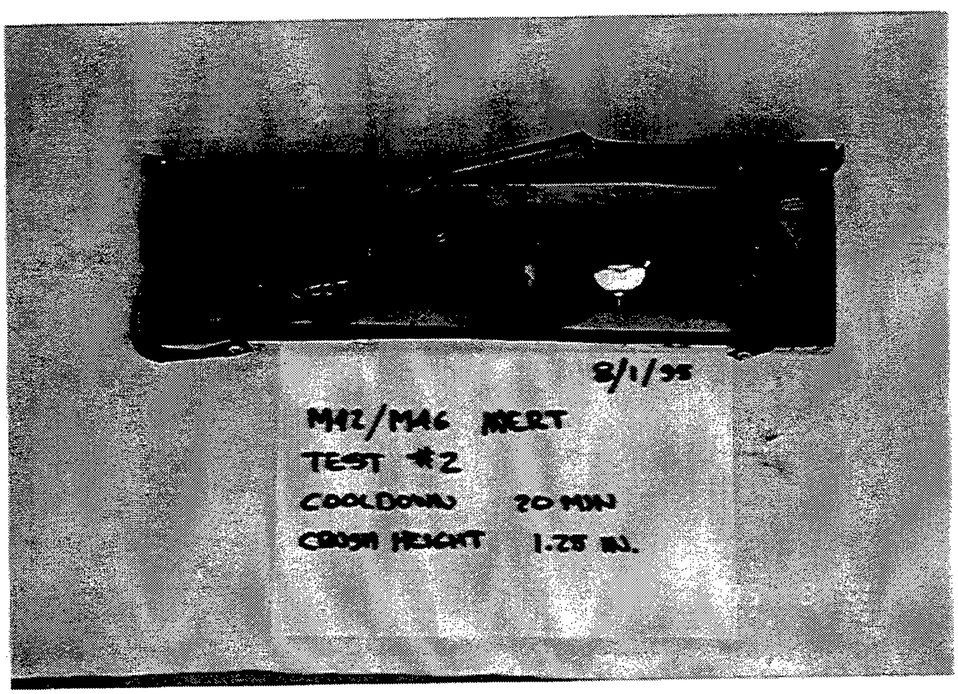


Figure 19
Debris from inert M42/M46 grenade test 2

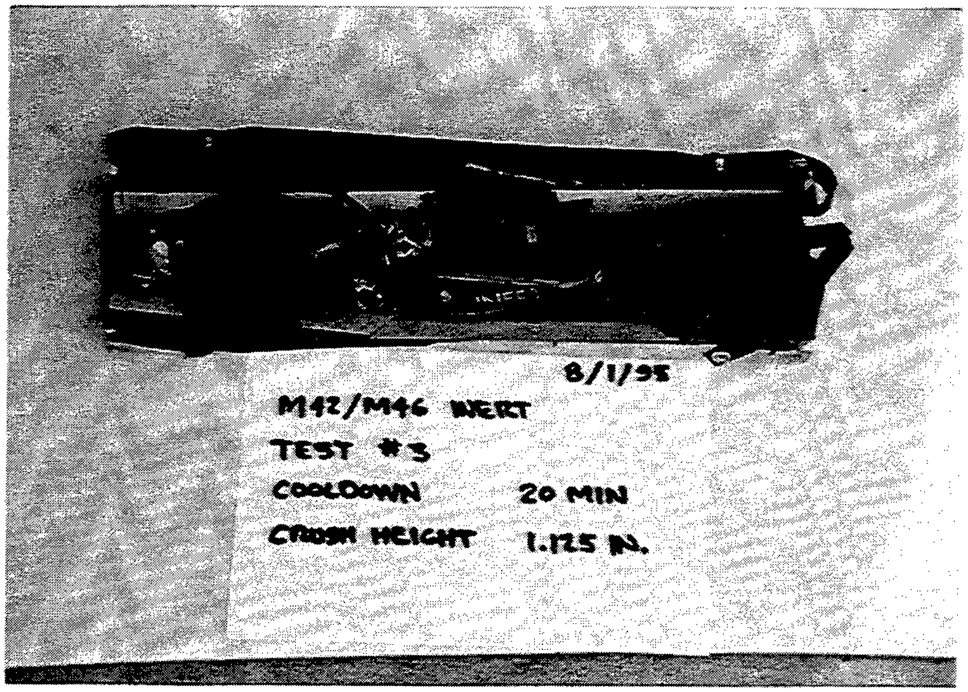


Figure 20
Debris from inert M42/M46 grenade test 3

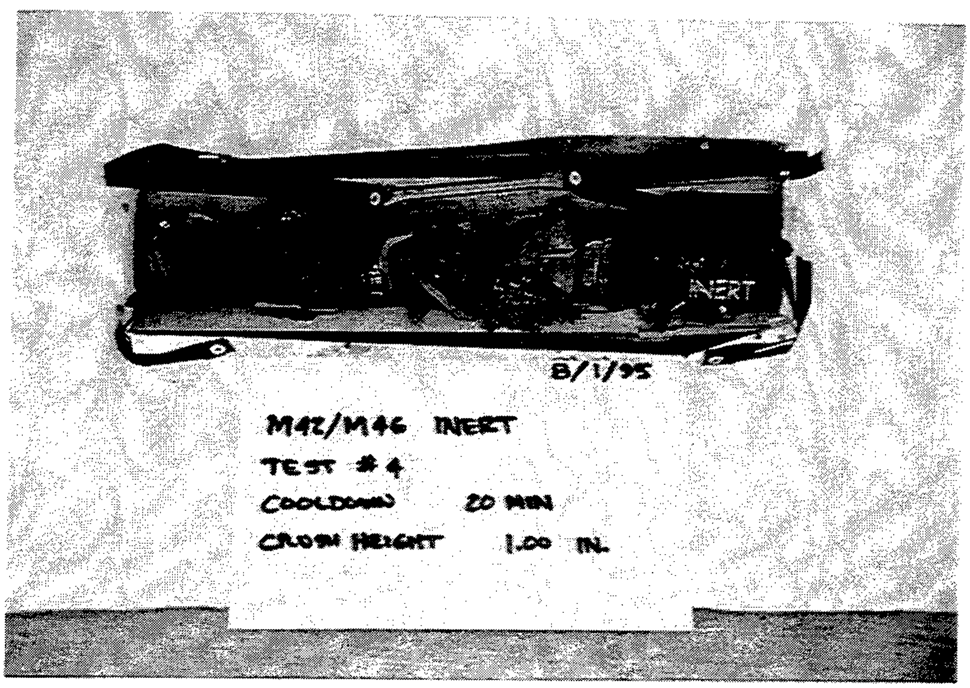


Figure 21
Debris from inert M42/M46 grenade test 4

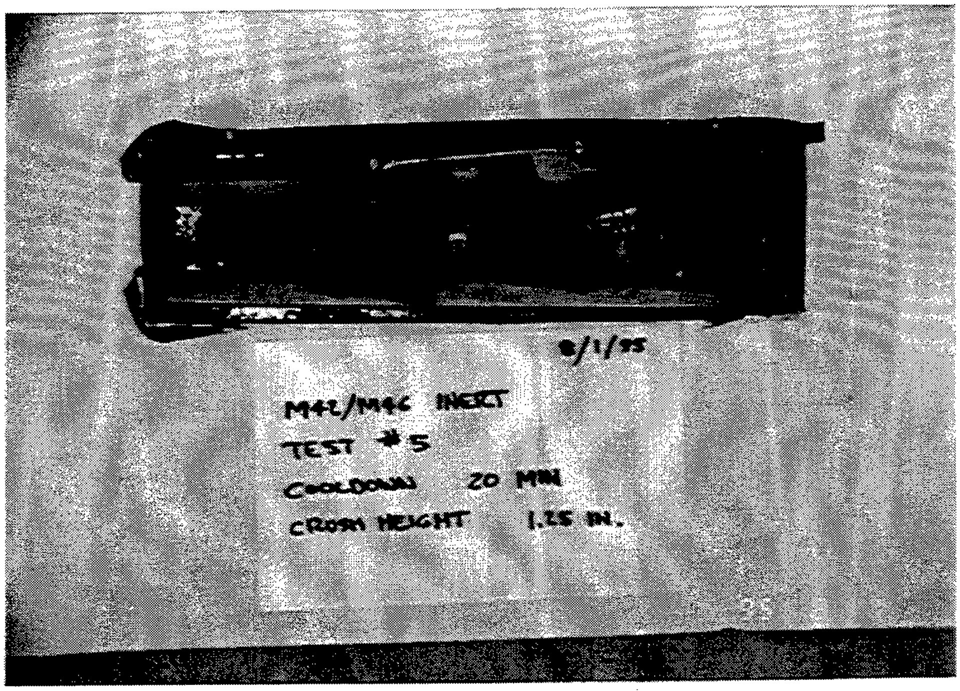


Figure 22
Debris from inert M42/M46 grenade test 5

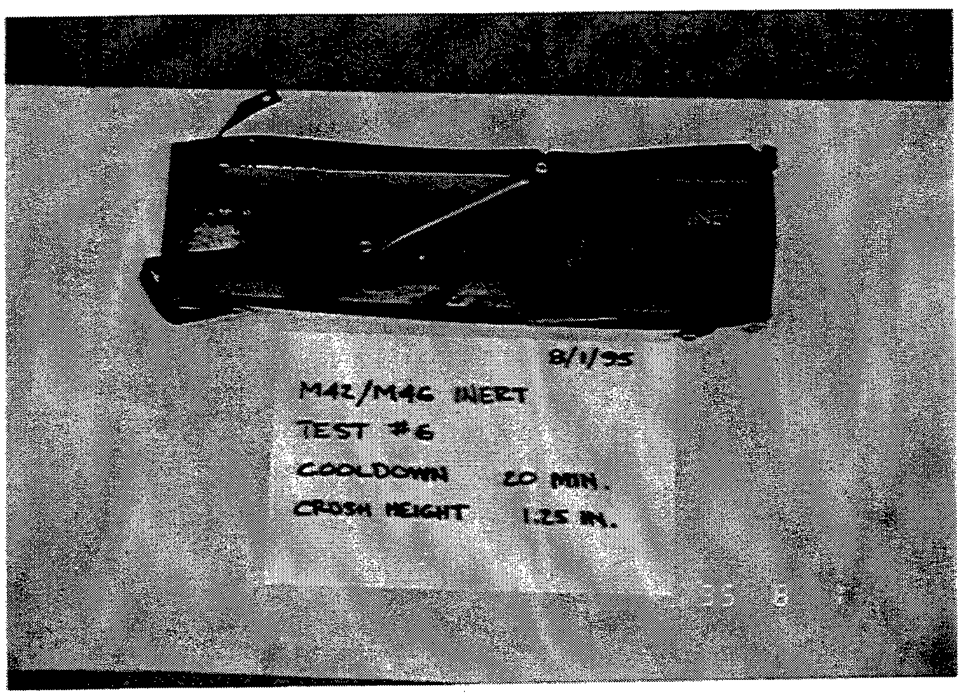


Figure 23
Debris from inert M42/M46 grenade test 6

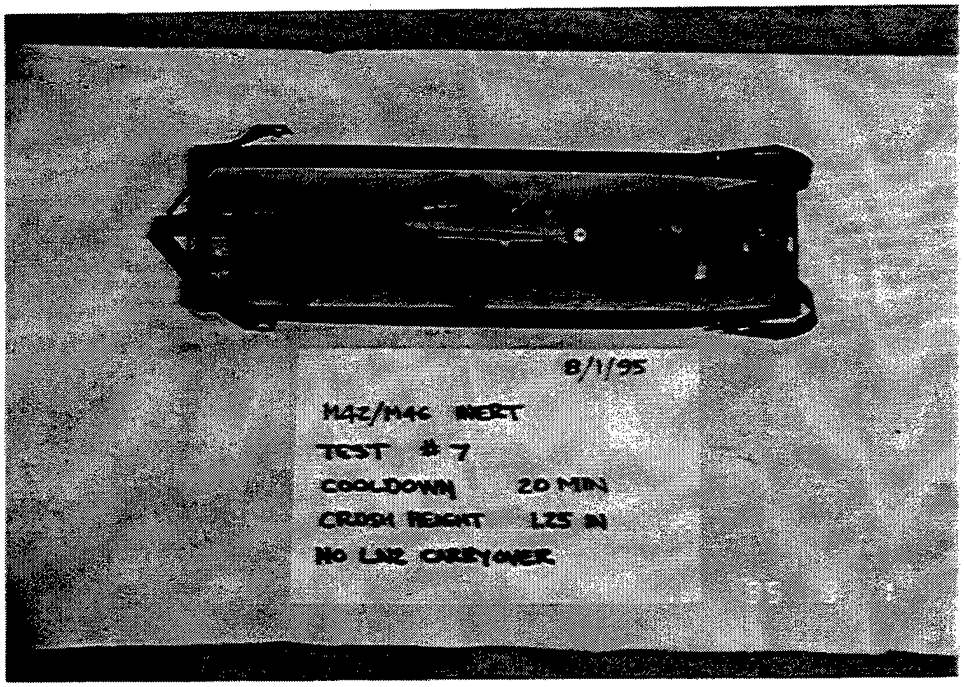


Figure 24
Debris from inert M42/M46 grenade test 7

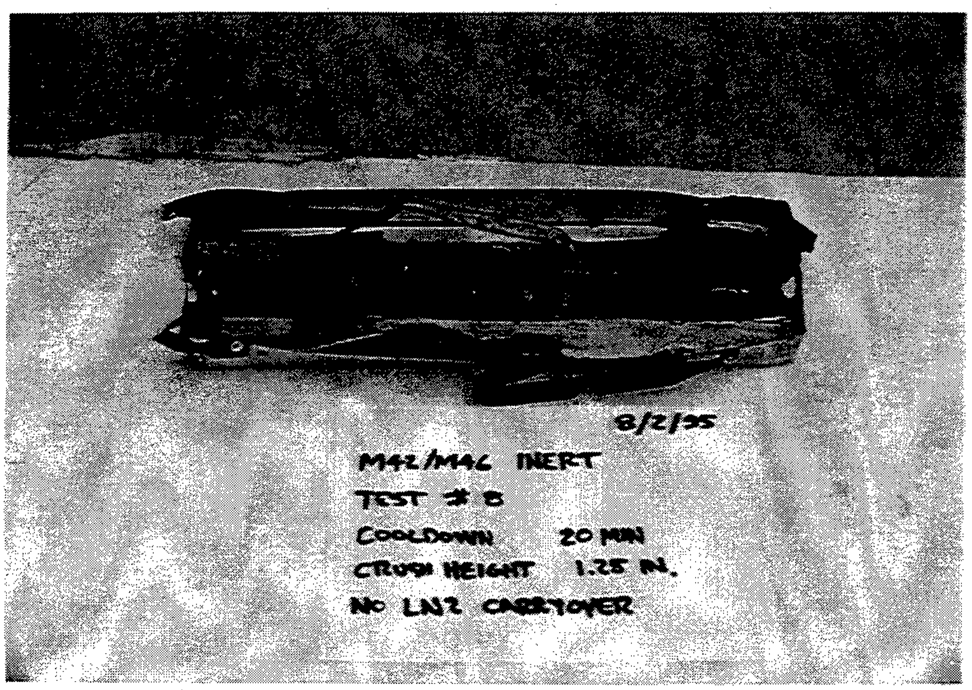


Figure 25
Debris from inert M42/M46 grenade test 8

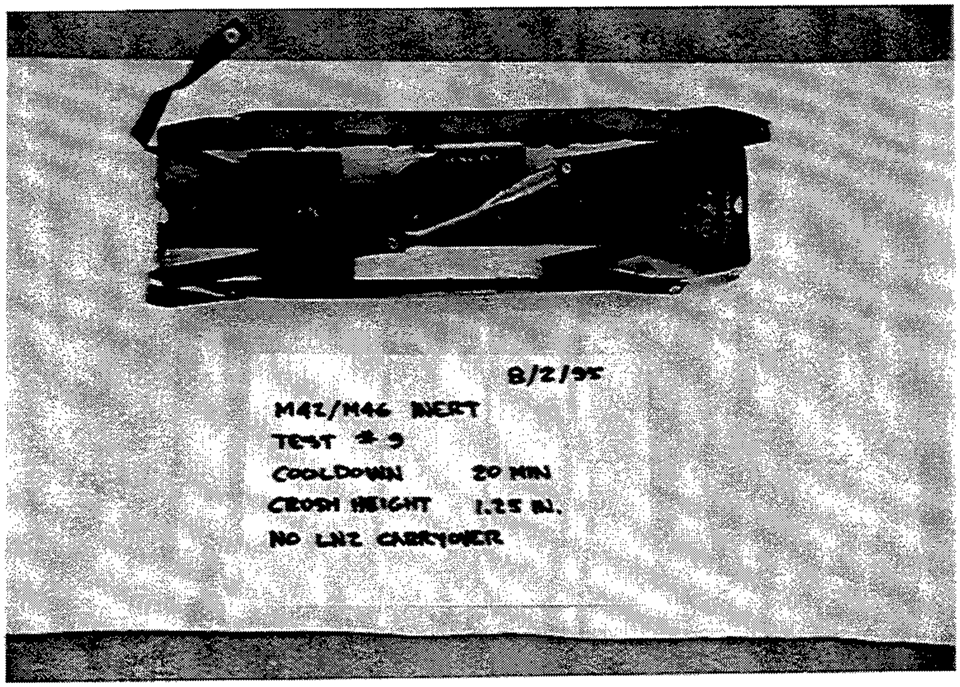


Figure 26
Debris from inert M42/M46 grenade test 9

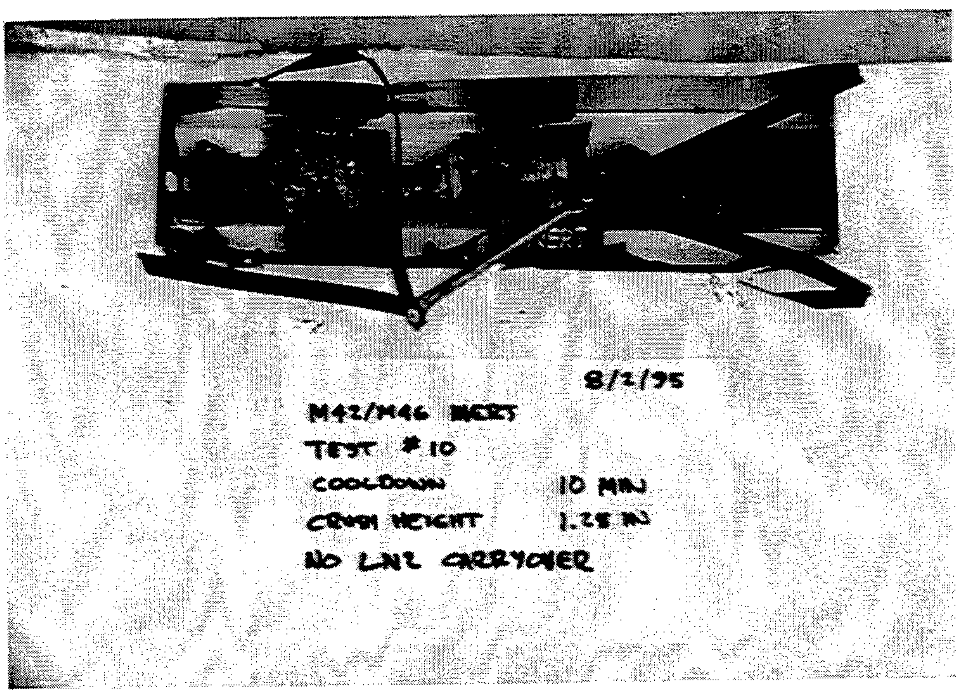


Figure 27
Debris from inert M42/M46 grenade test 10

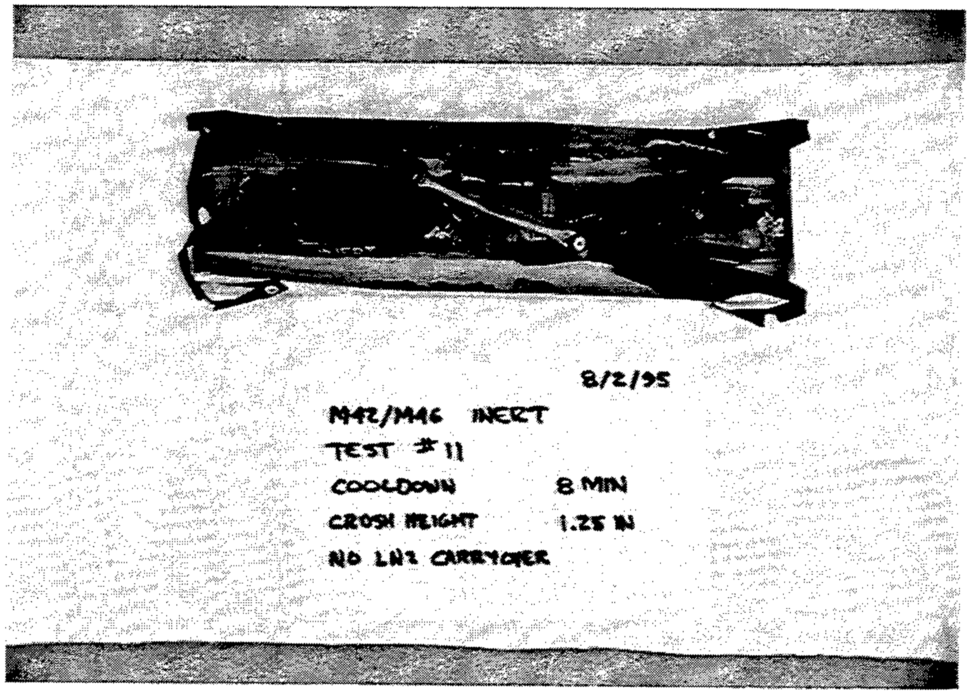


Figure 28
Debris from inert M42/M46 grenade test 11

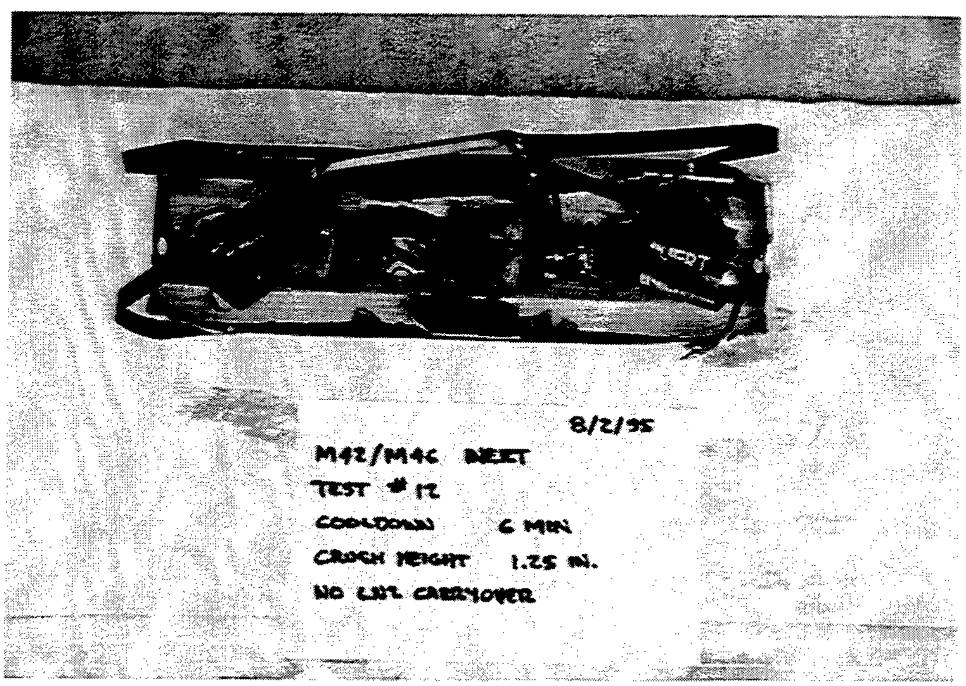


Figure 29
Debris from inert M42/M46 grenade test 12

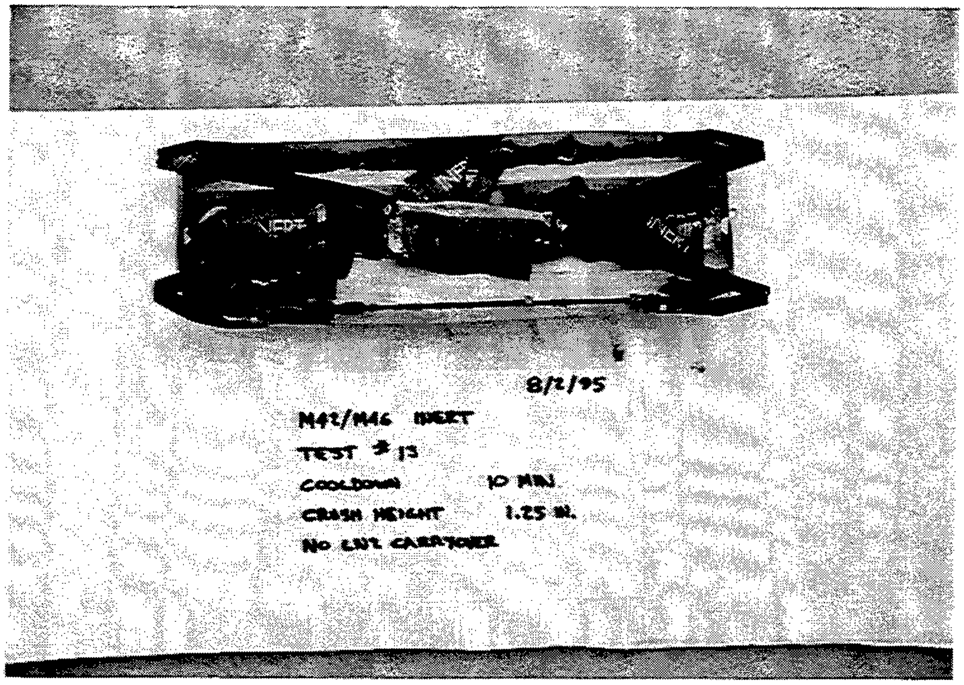


Figure 30
Debris from inert M42/M46 grenade test 13

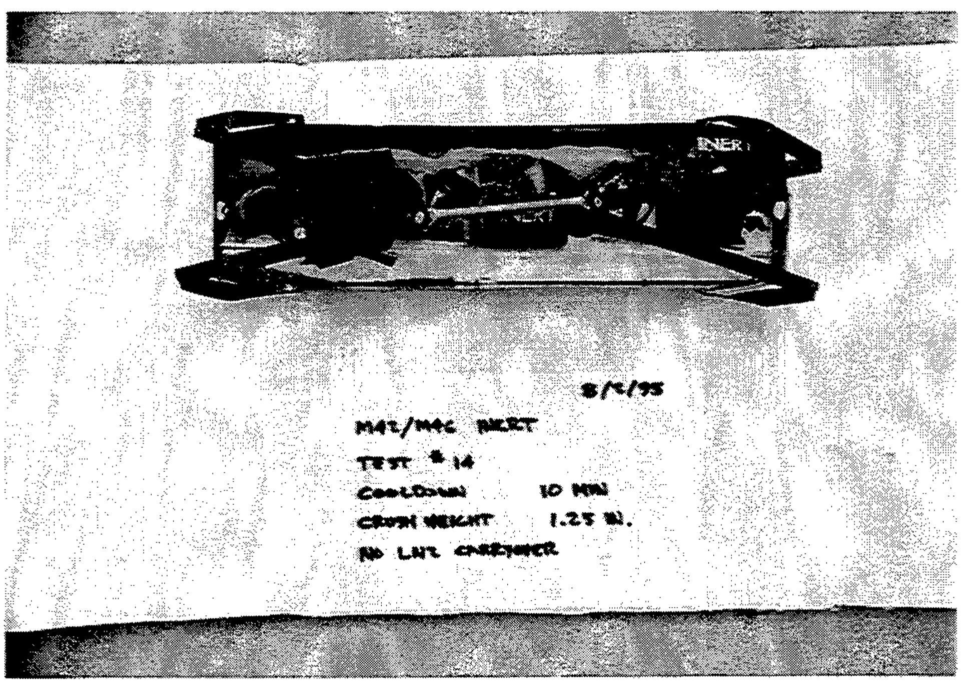


Figure 31
Debris from inert M42/M46 grenade test 14

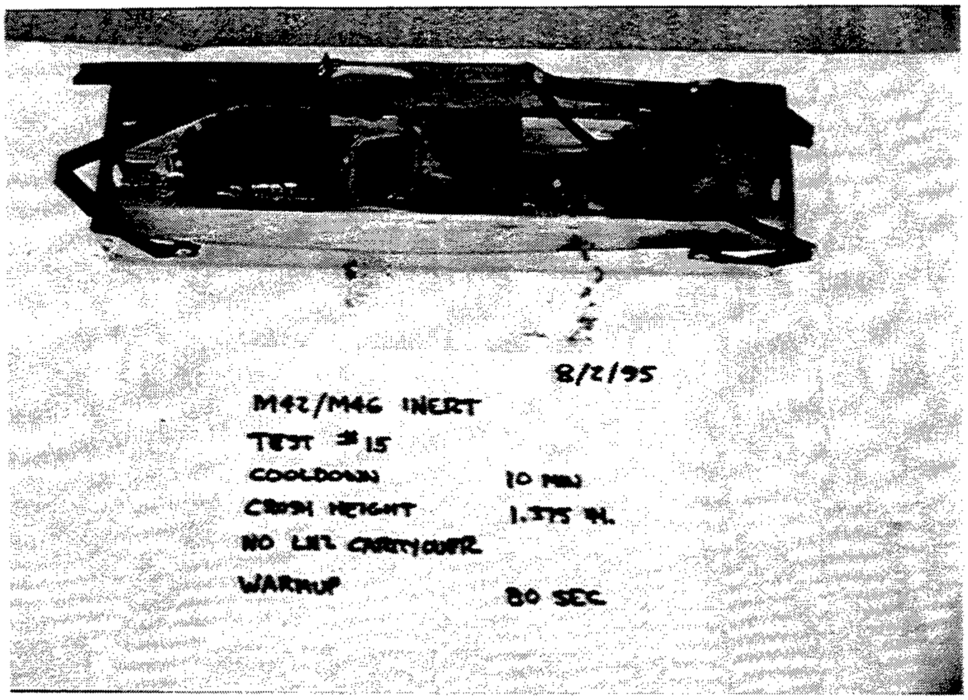


Figure 32
Debris from inert M42/M46 grenade test 15

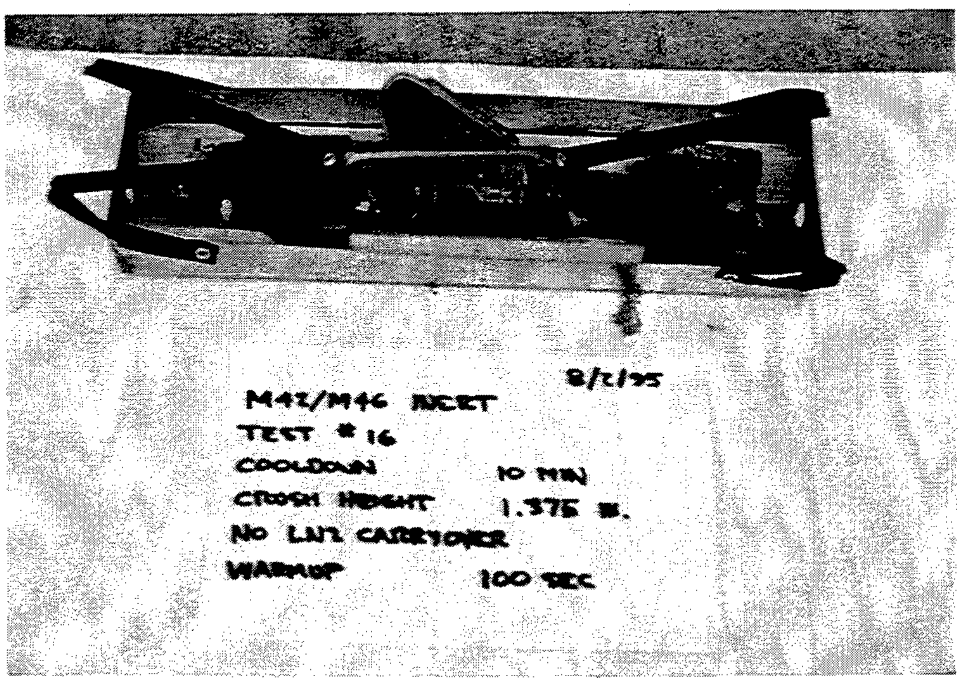


Figure 33
Debris from inert M42/M46 grenade test 16

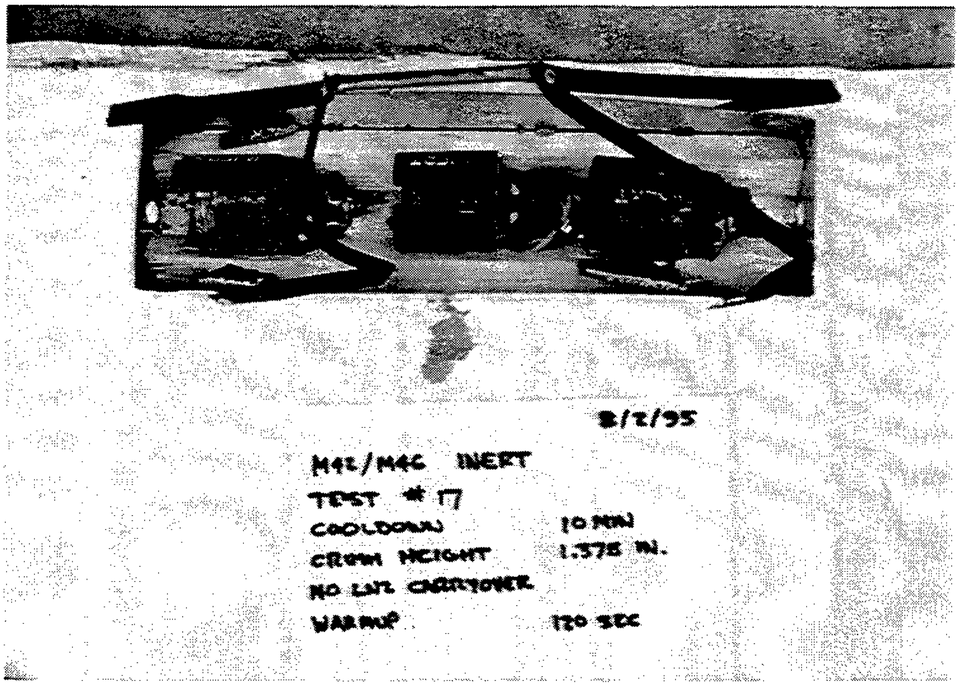


Figure 34
Debris from inert M42/M46 grenade test 17

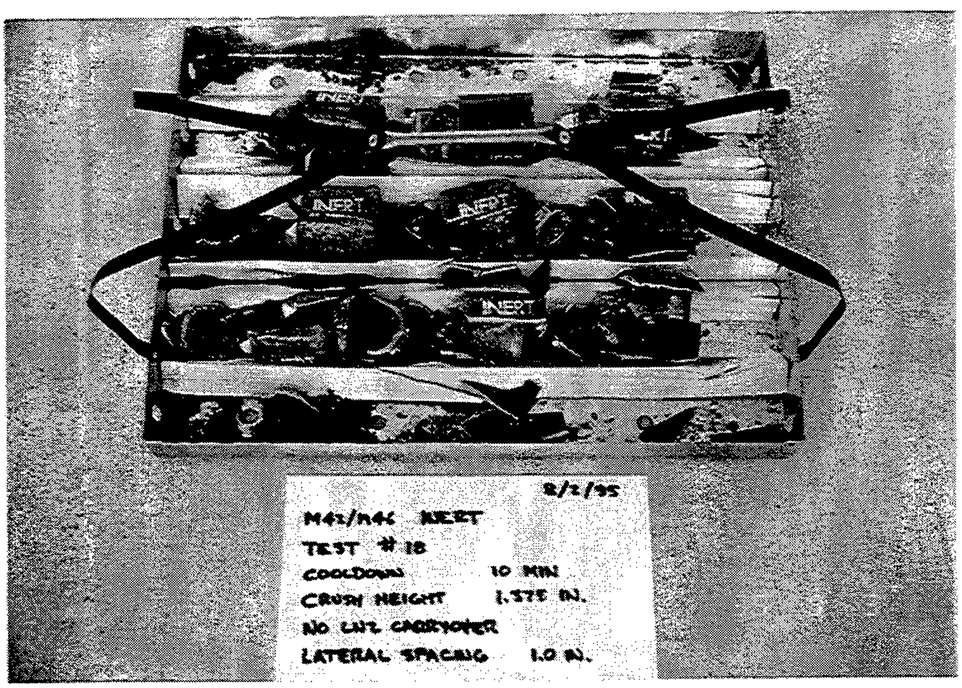


Figure 35
Debris from inert M42/M46 grenade test 18

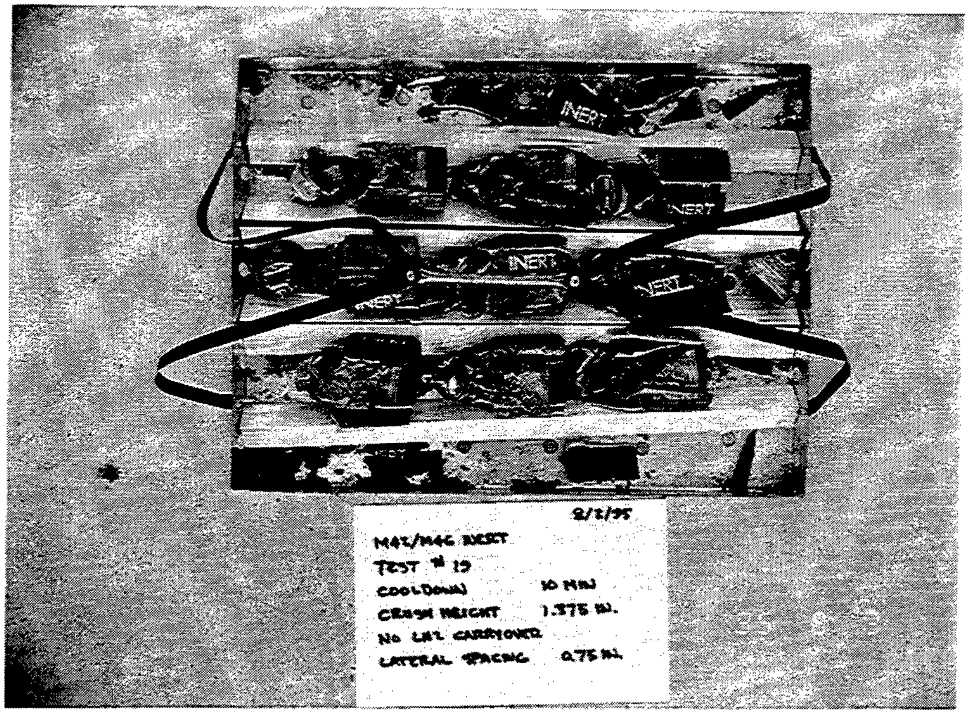


Figure 36
Debris from inert M42/M46 grenade test 19

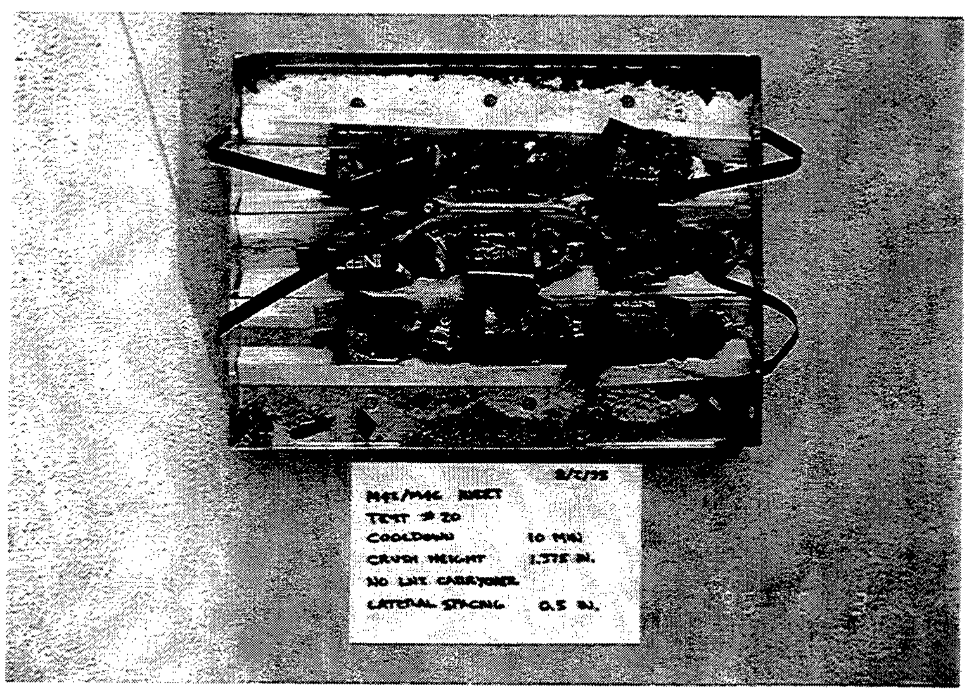


Figure 37
Debris from inert M42/M46 grenade test 20

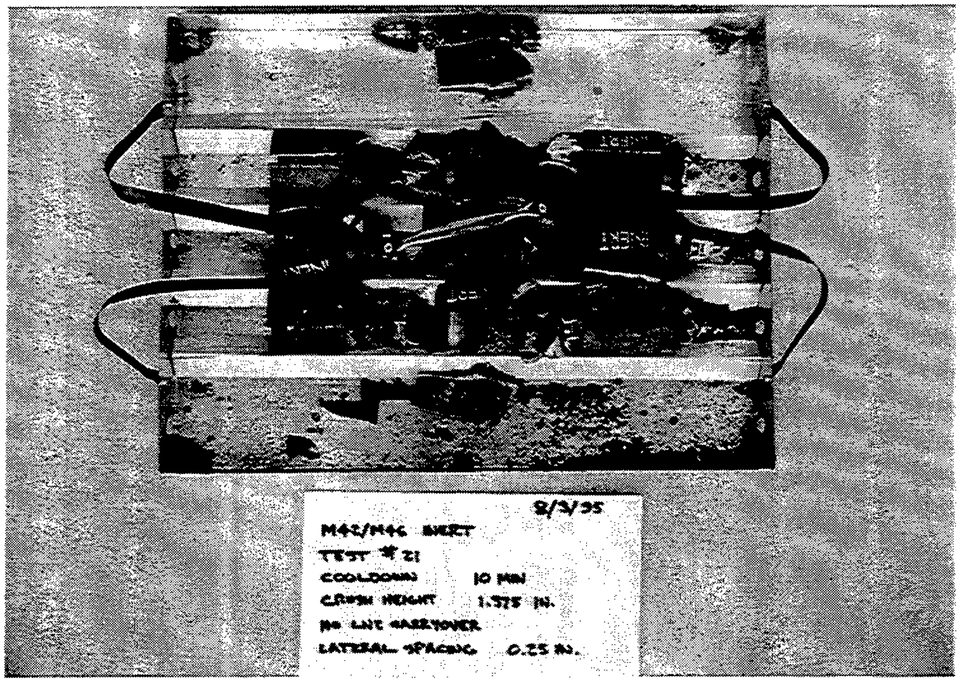


Figure 38
Debris from inert M42/M46 grenade test 21

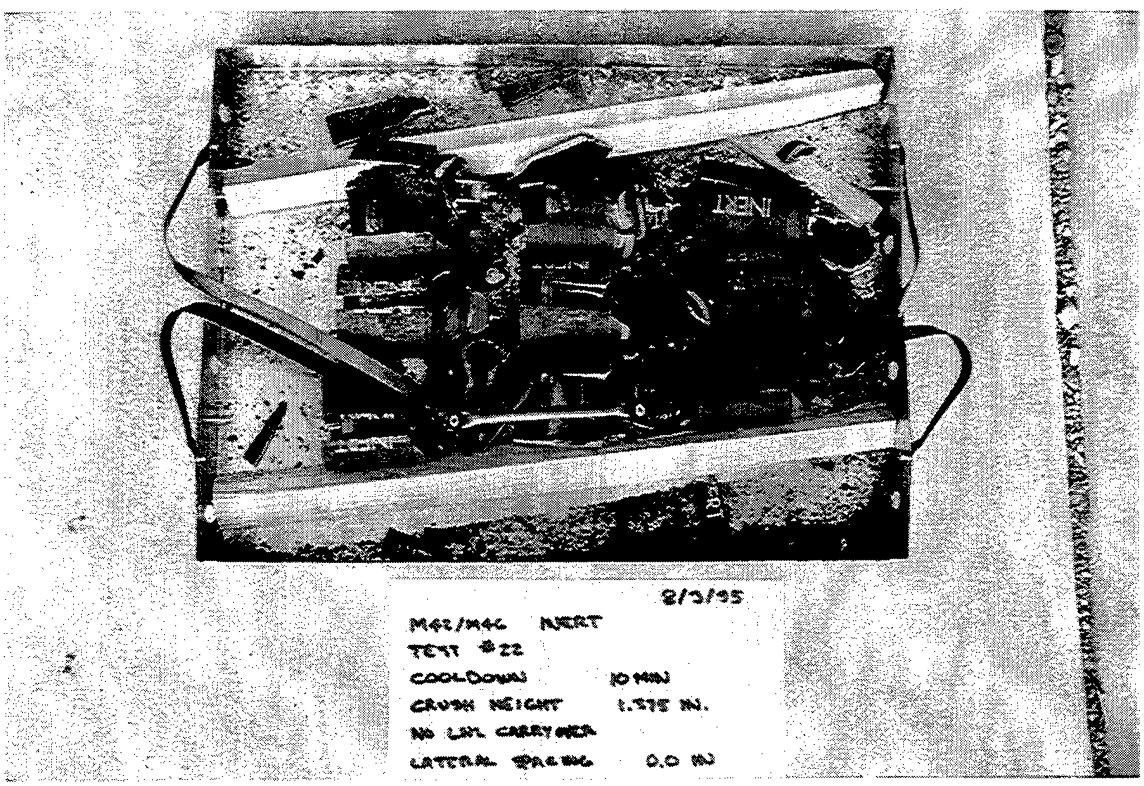


Figure 39
Debris from inert M42/M46 grenade test 22

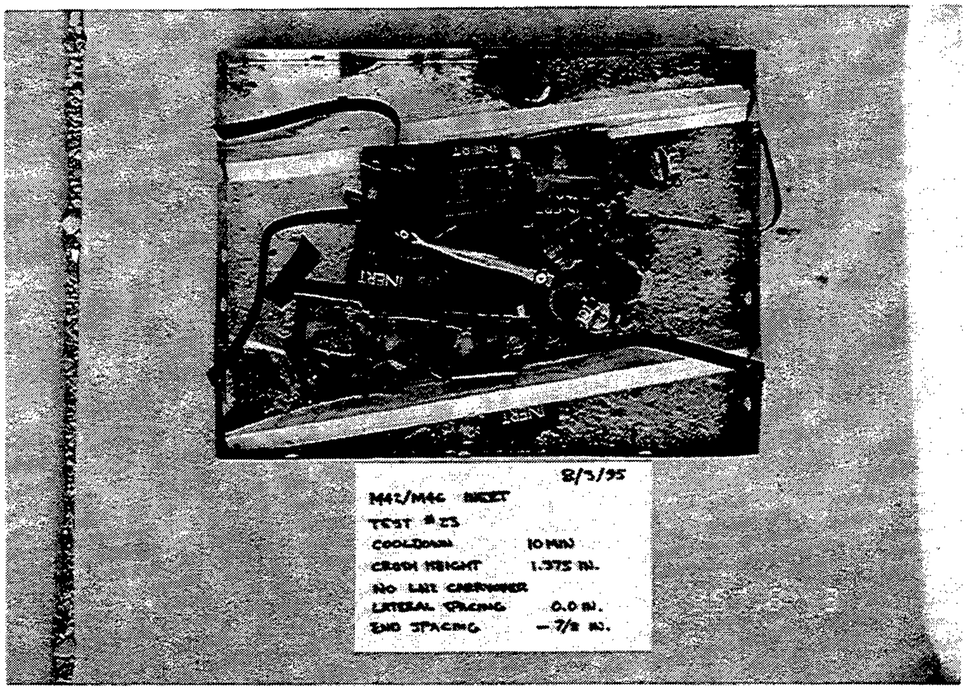


Figure 40
Debris from inert M42/M46 grenade test 23

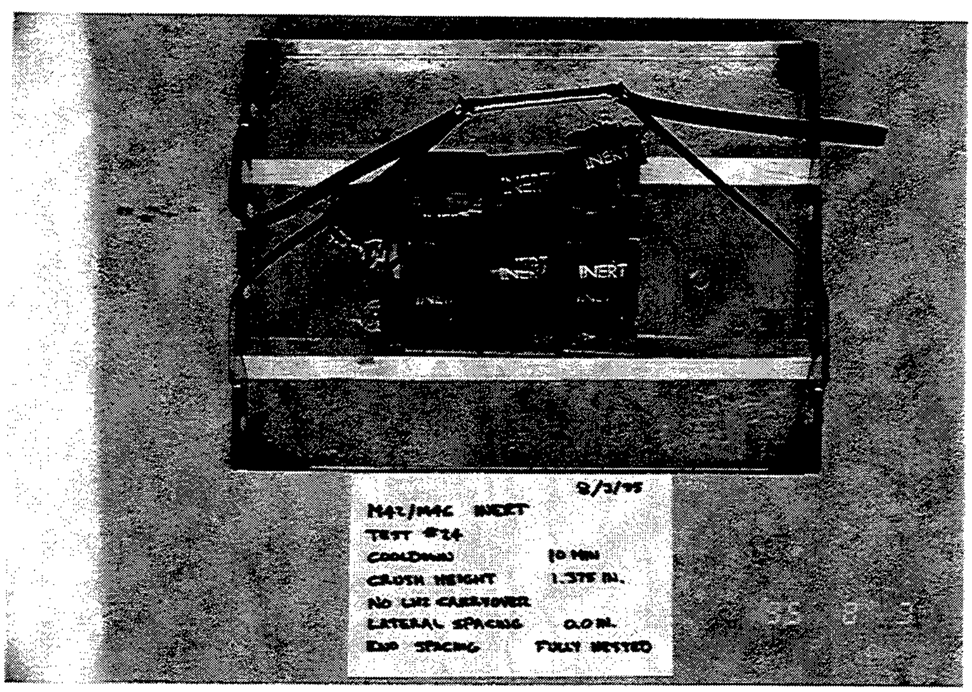


Figure 41
Debris from inert M42/M46 grenade test 24

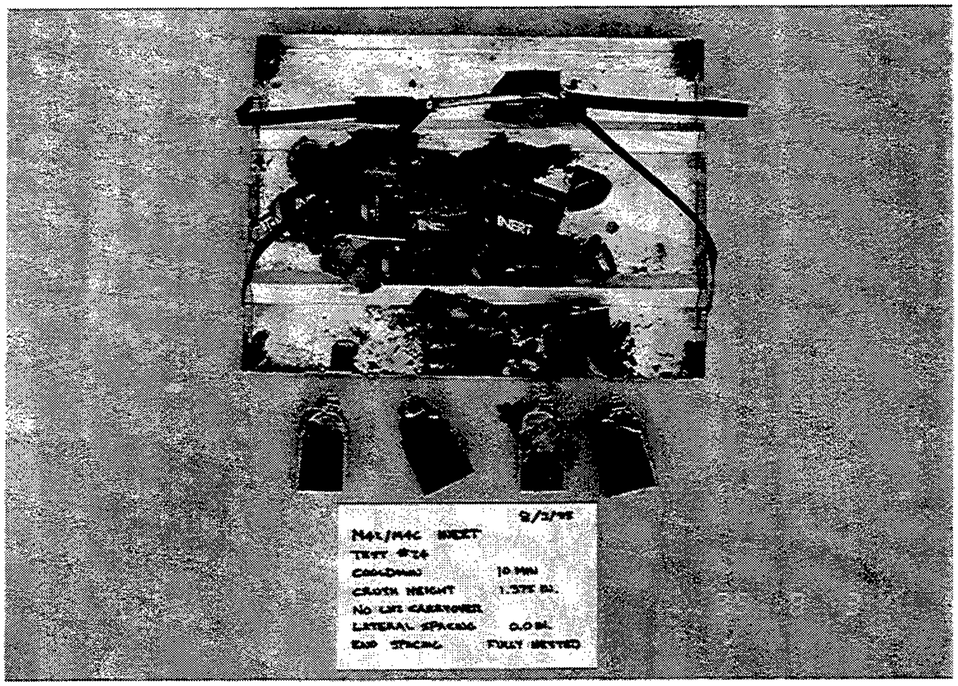


Figure 42
Debris from inert M42/M46 grenade test 24

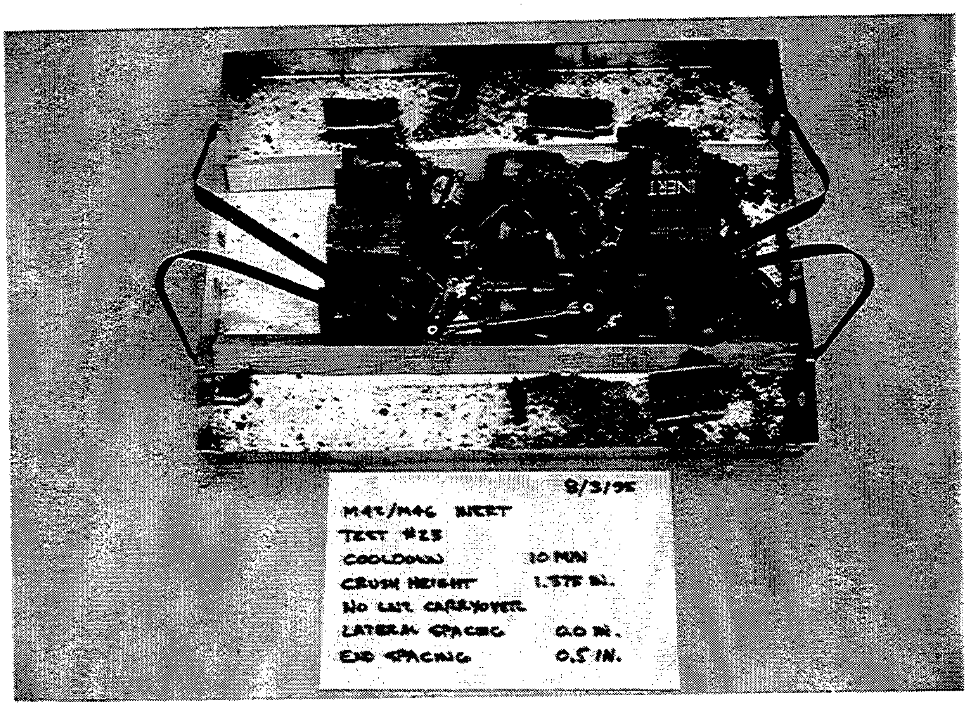


Figure 43
Debris from inert M42/M46 grenade test 25

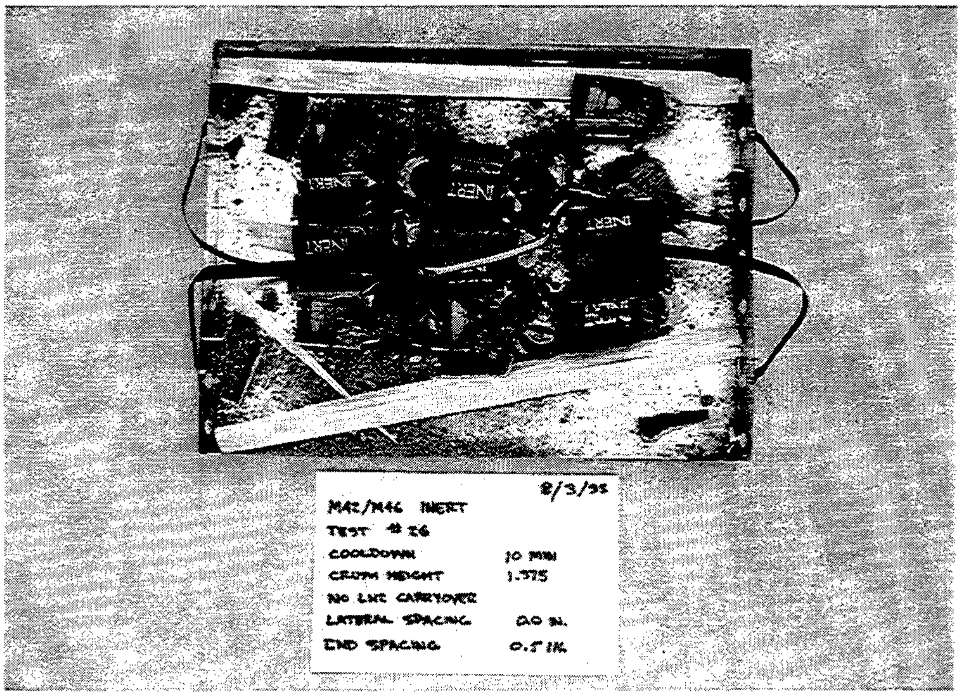


Figure 44
Debris from inert M42/M46 grenade test 26

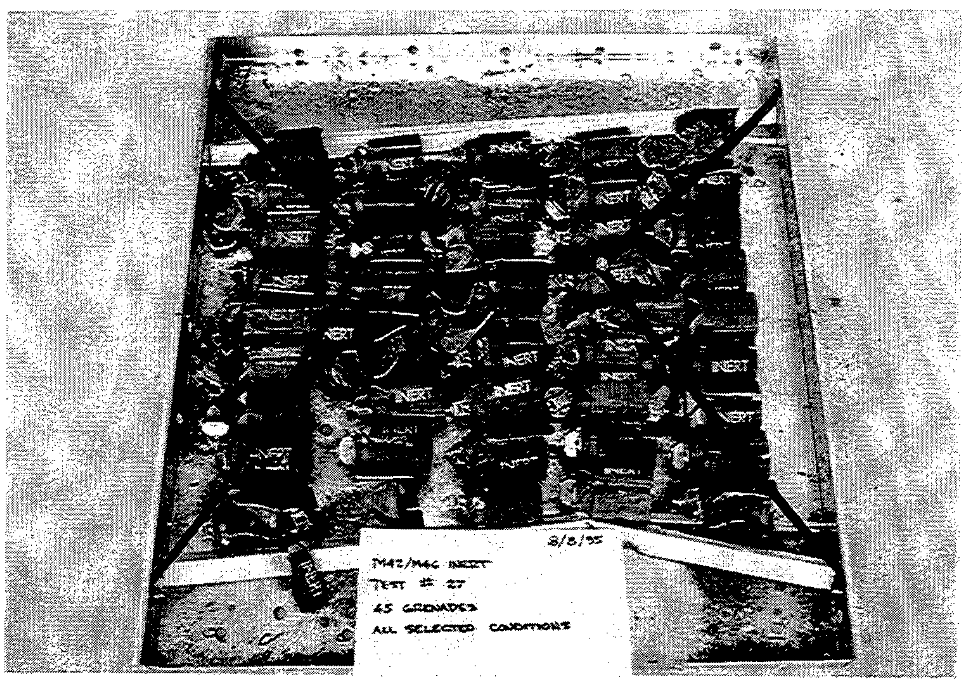


Figure 45
Debris from inert M42/M46 grenade test 27

Figure 46
Debris from inert M42/M46 grenade test 28

Figure 47
Debris from inert M42/M46 grenade test 29

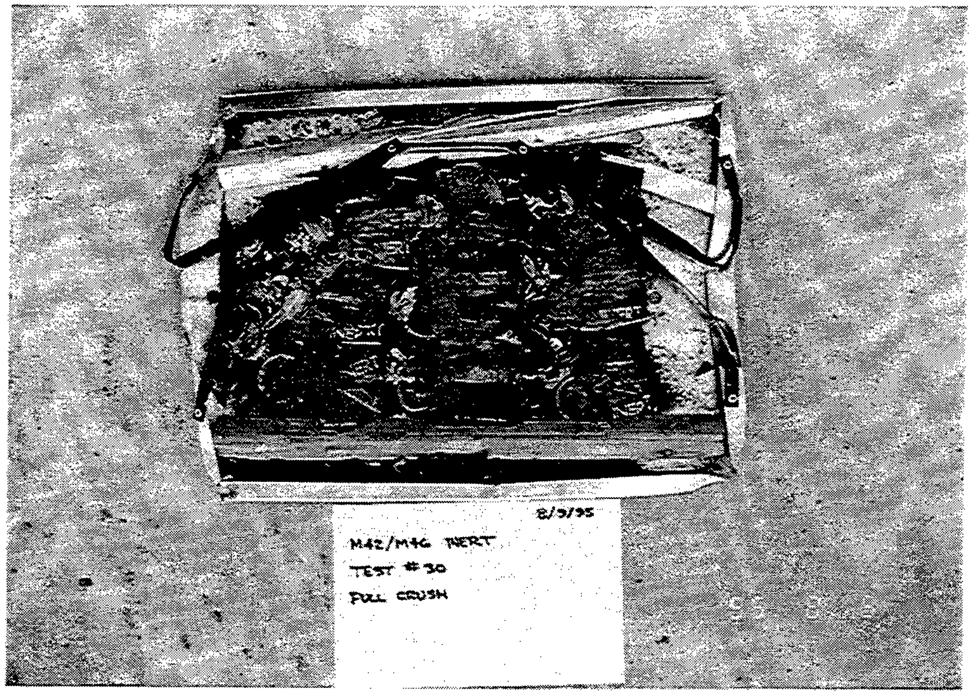


Figure 48
Debris from inert M42/M46 grenade test 30

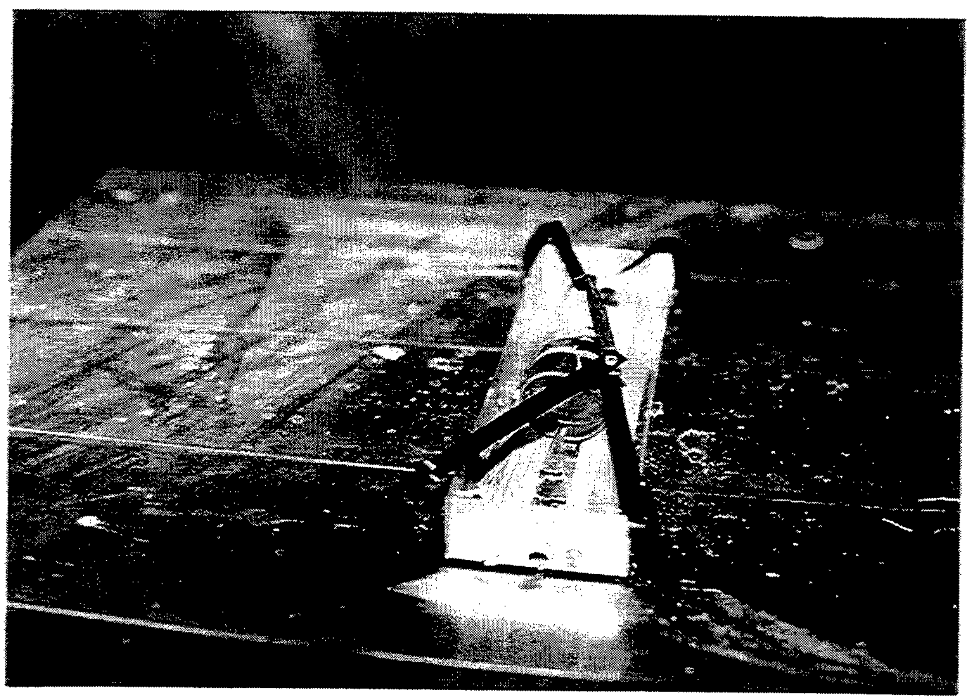


Figure 49
Debris from live M77 grenade test 1

Figure 50
Debris from live M77 grenade test 1

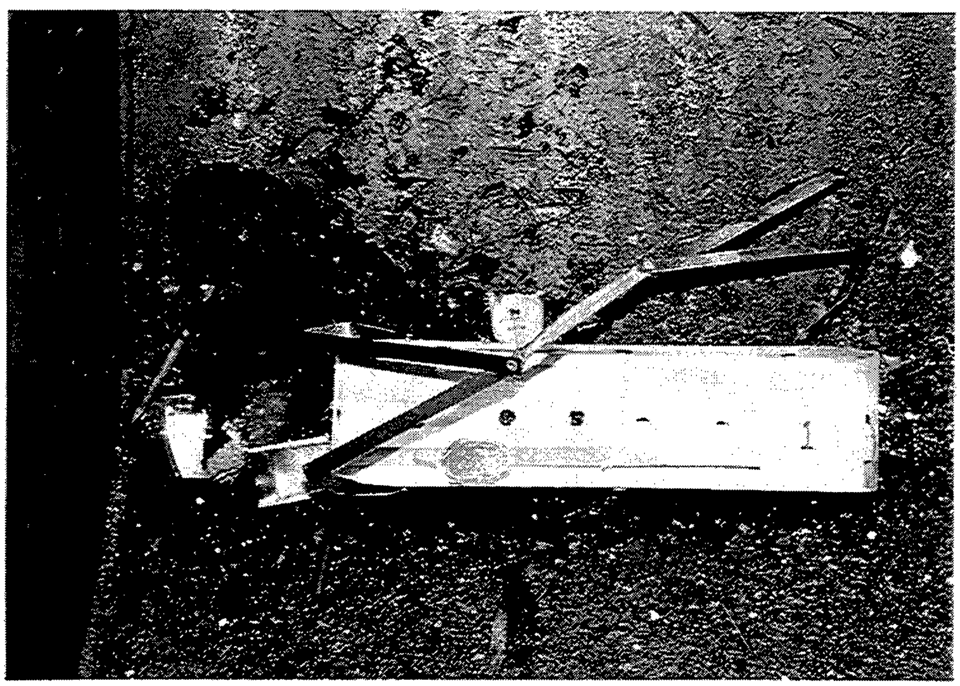


Figure 51
Debris from live M77 grenade test 1

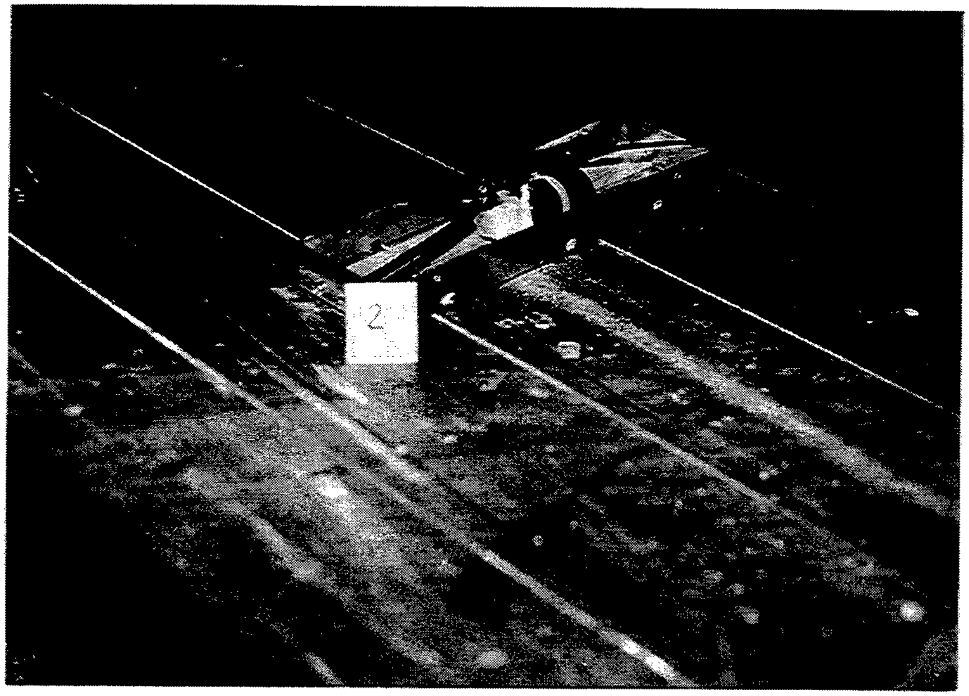


Figure 52
Debris from live M77 grenade test 2

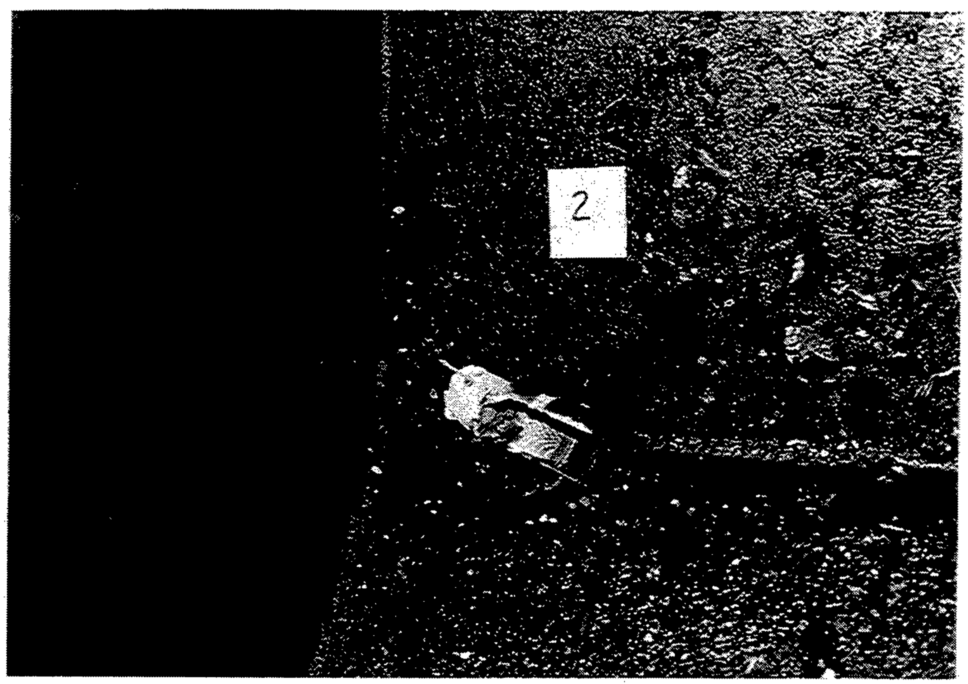


Figure 53
Debris from live M77 grenade test 2

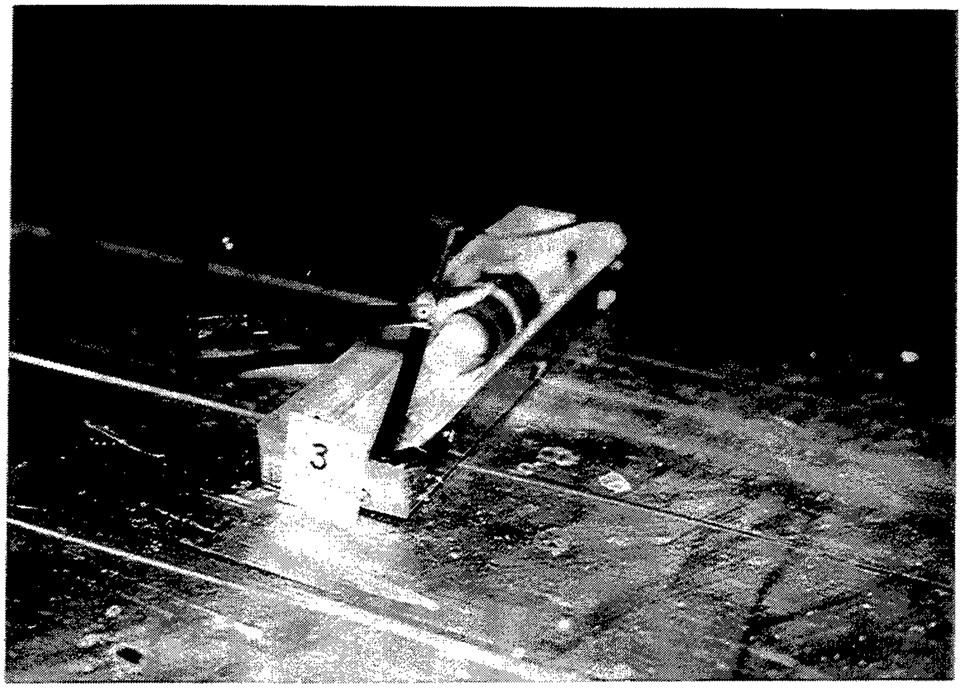


Figure 54
Debris from live M77 grenade test 3

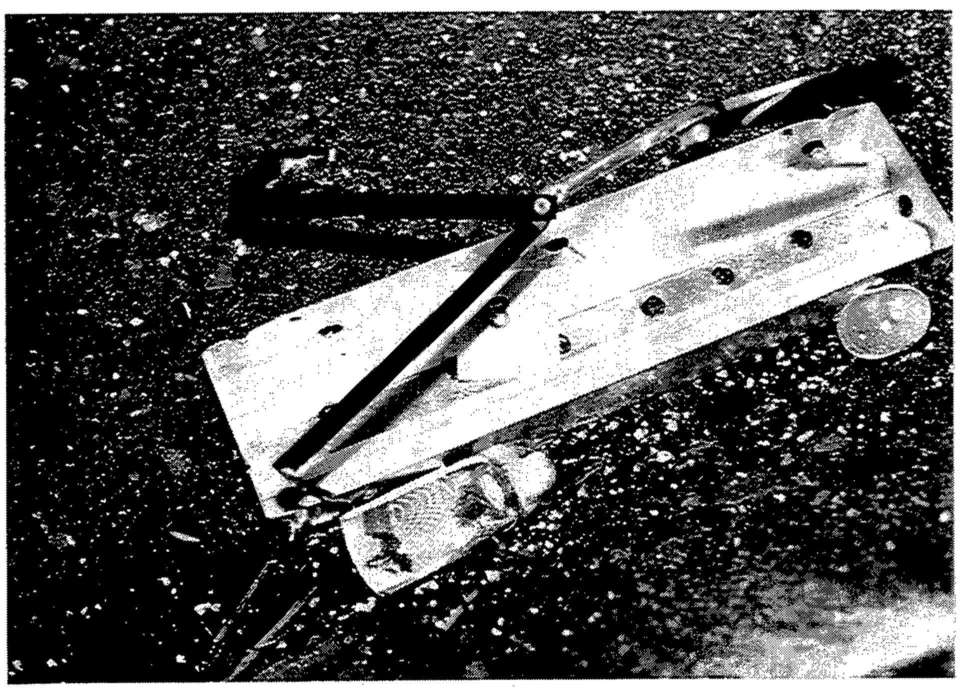


Figure 55
Debris from live M77 grenade test 3

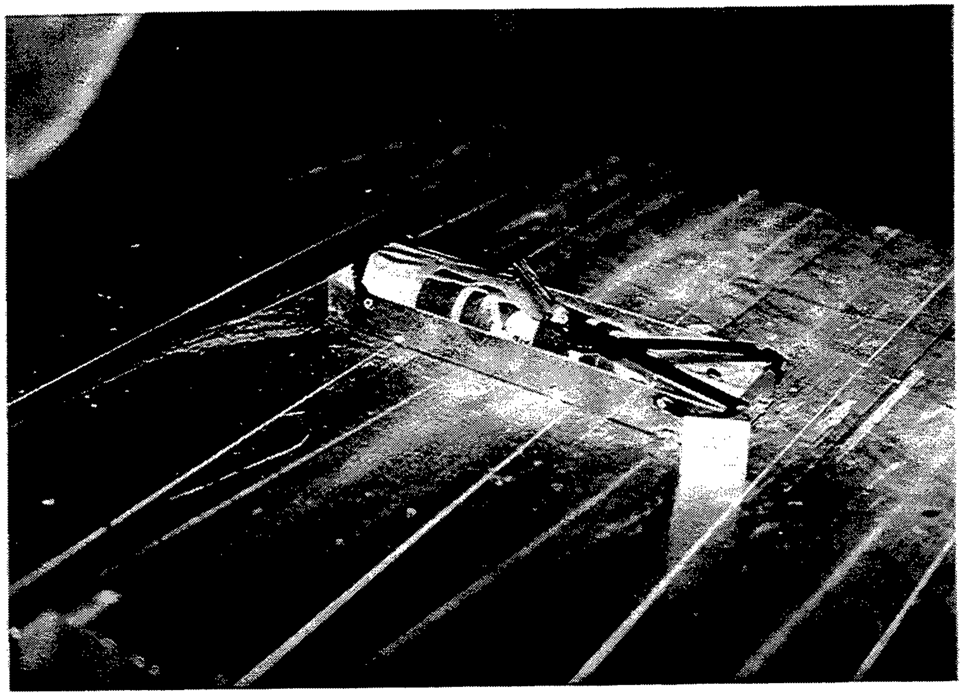


Figure 56
Debris from live M77 grenade test 4

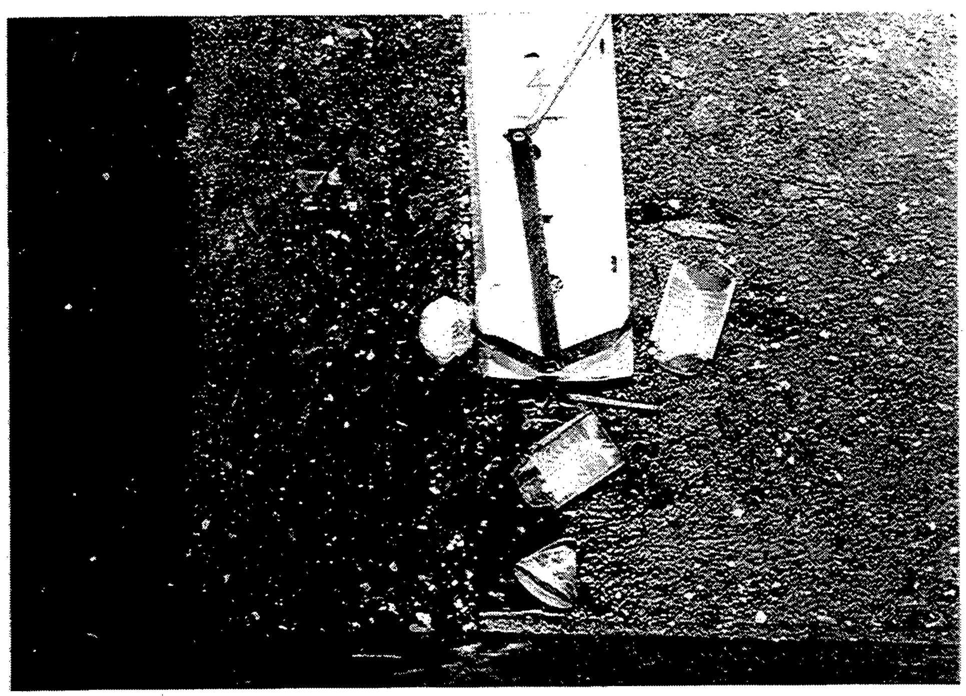


Figure 57
Debris from live M77 grenade test 4

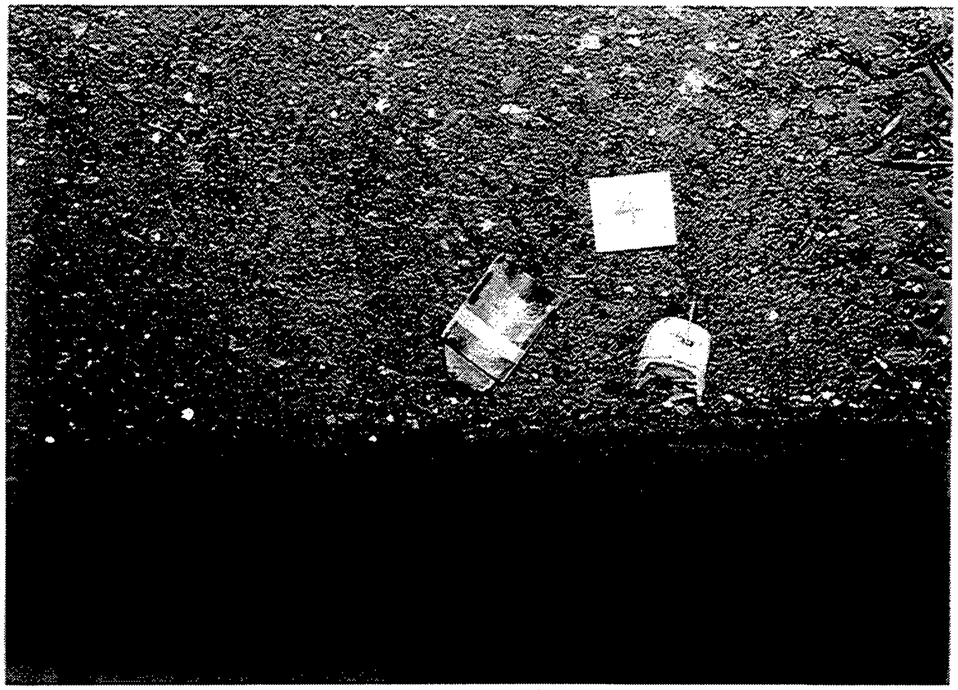


Figure 58
Debris from live M77 grenade test 4

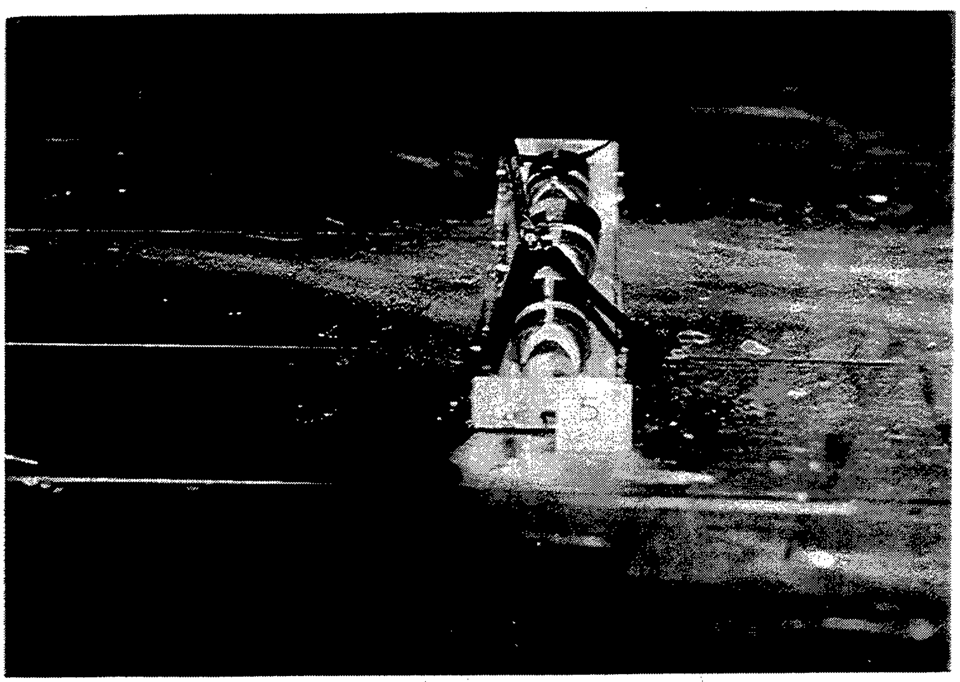


Figure 59
Debris from live M77 grenade test 5

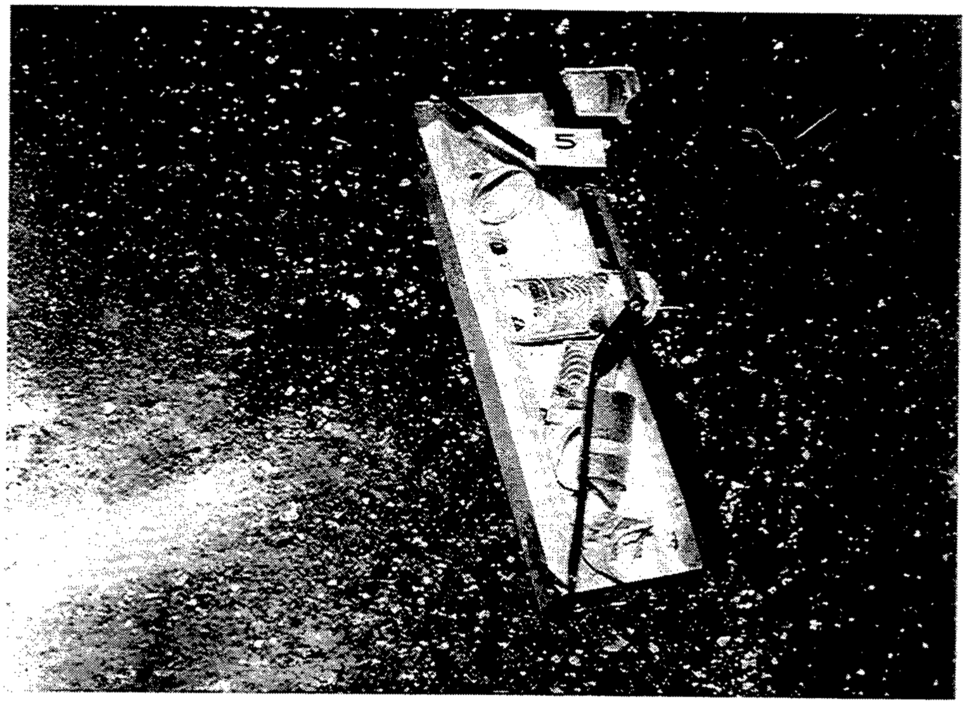


Figure 60
Debris from live M77 grenade test 5

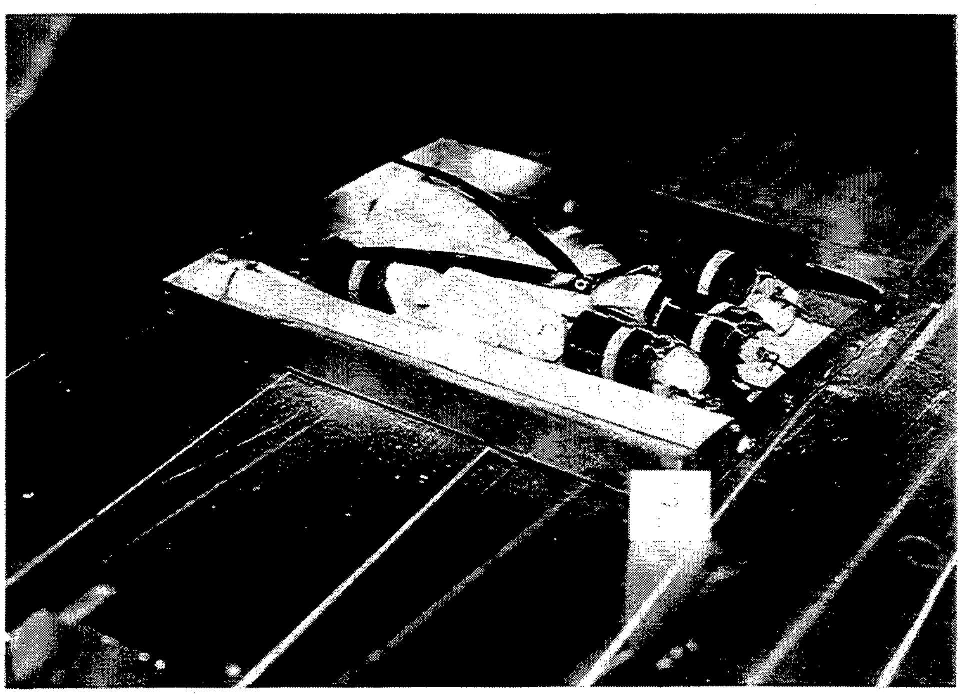


Figure 61
Debris from live M77 grenade test 6

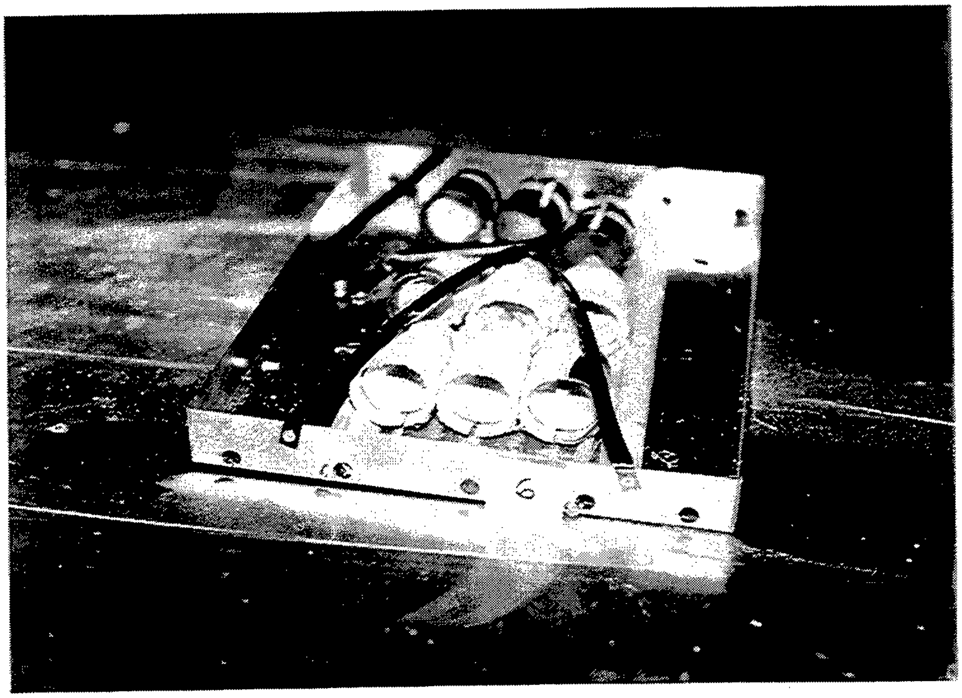


Figure 62
Debris from live M77 grenade test 6

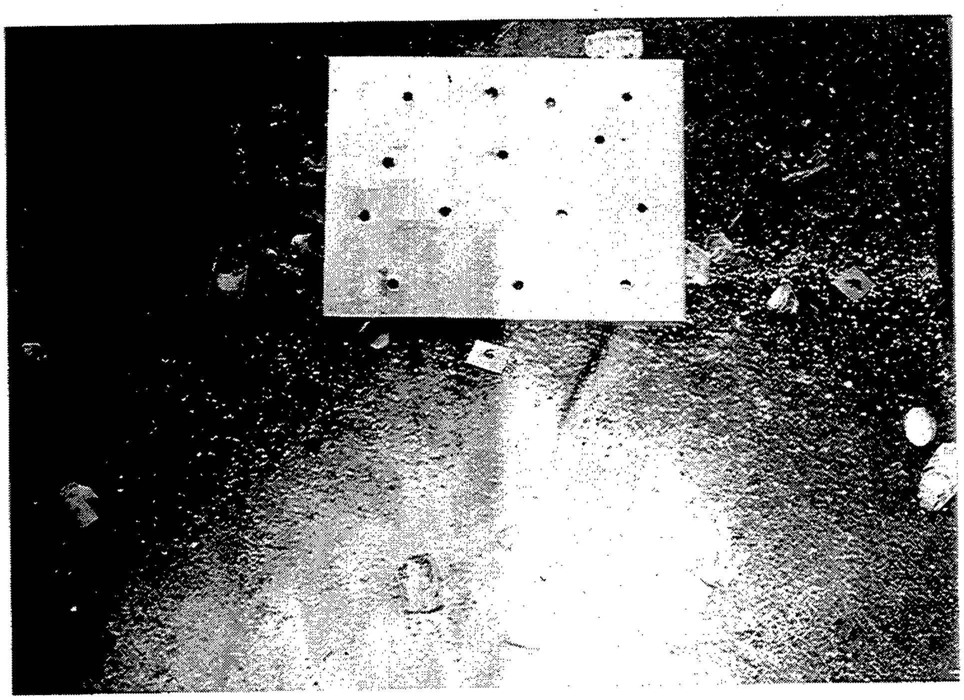


Figure 63
Debris from live M77 grenade test 6

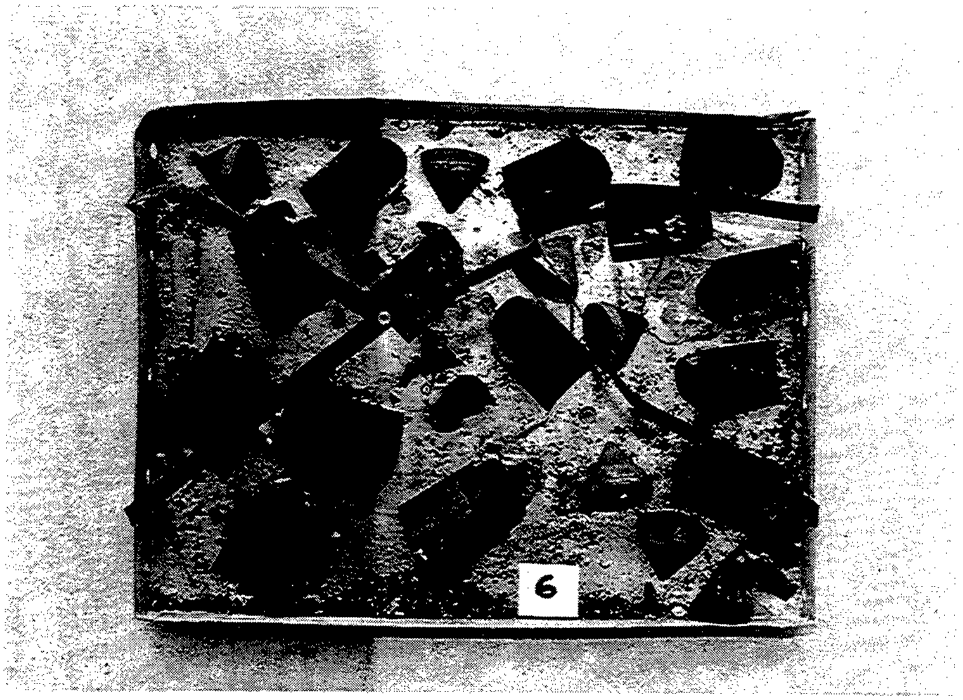


Figure 64
Debris from live M77 grenade test 6

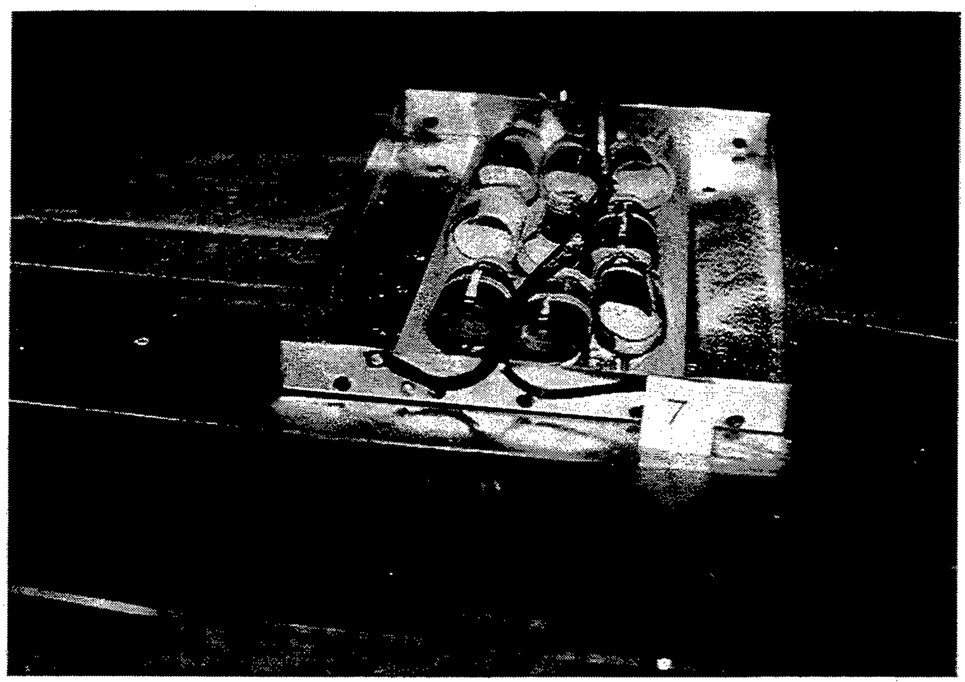


Figure 65
Debris from live M77 grenade test 7

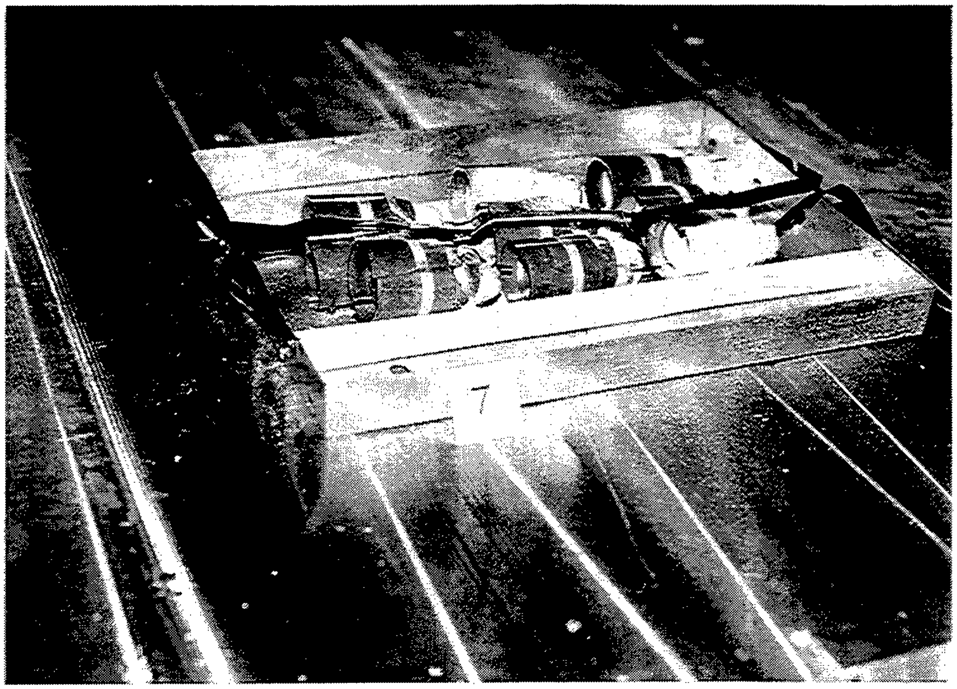


Figure 66
Debris from live M77 grenade test 7

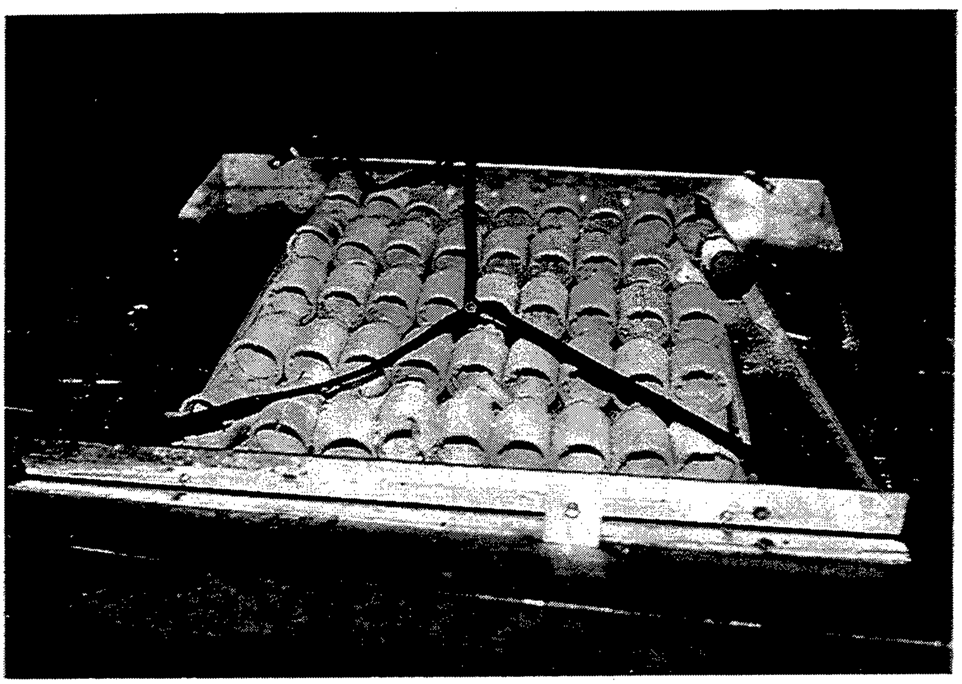


Figure 67
Debris from live M77 grenade test 8

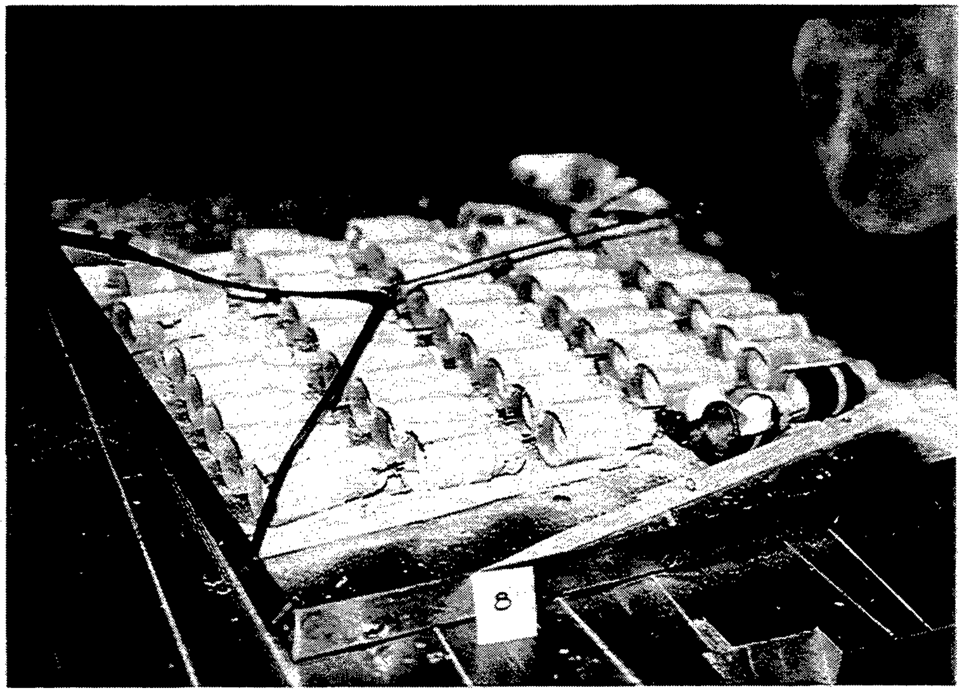


Figure 68
Debris from live M77 grenade test 8

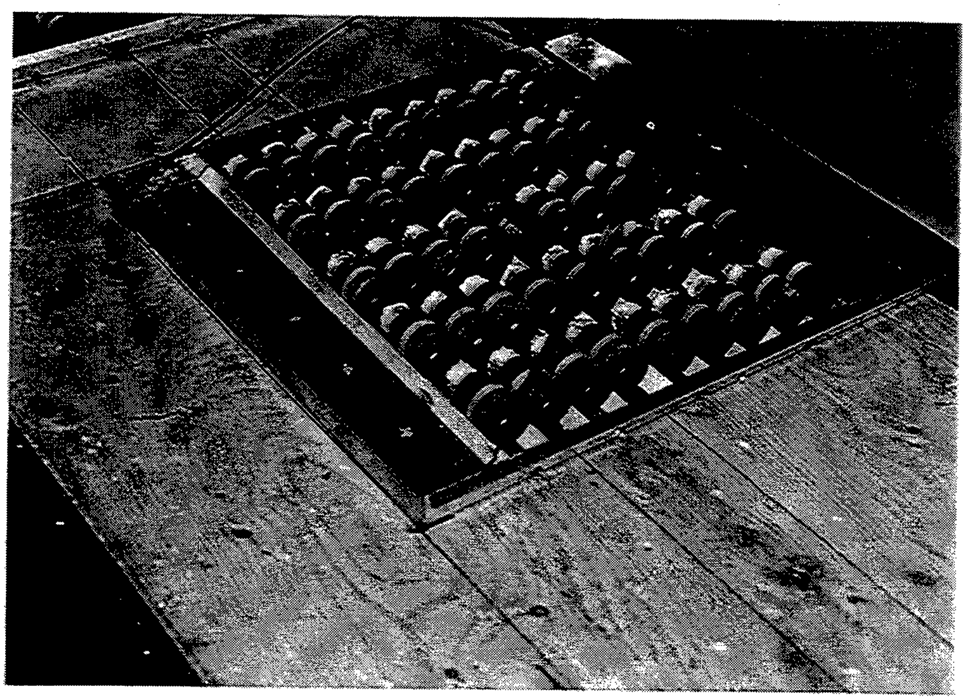


Figure 69
Loaded munitions handling basket for live M77 grenade test 9

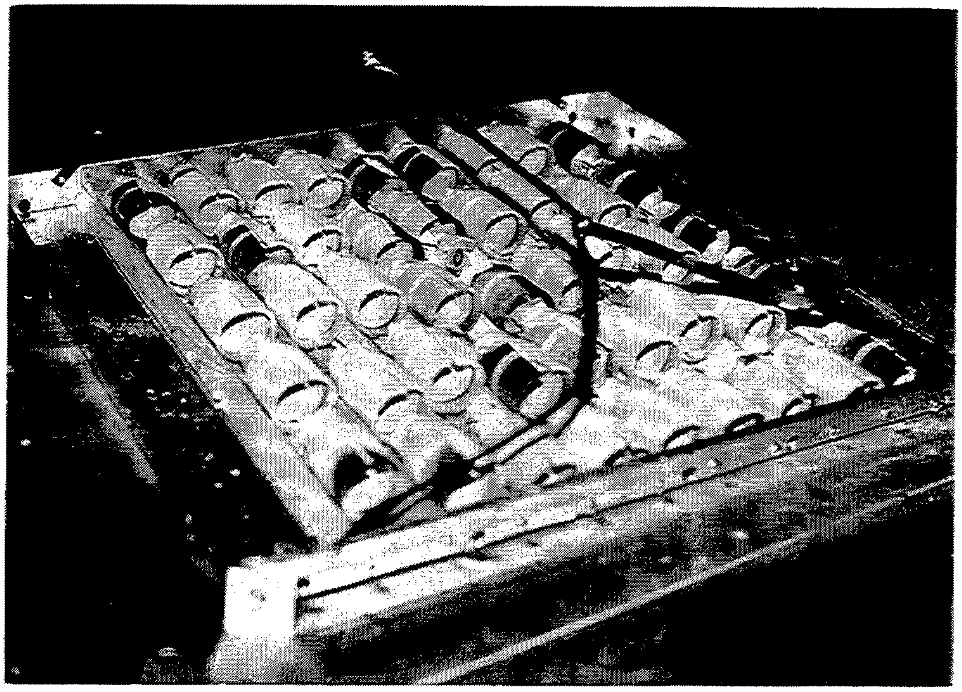


Figure 70
Debris from live M77 grenade test 9

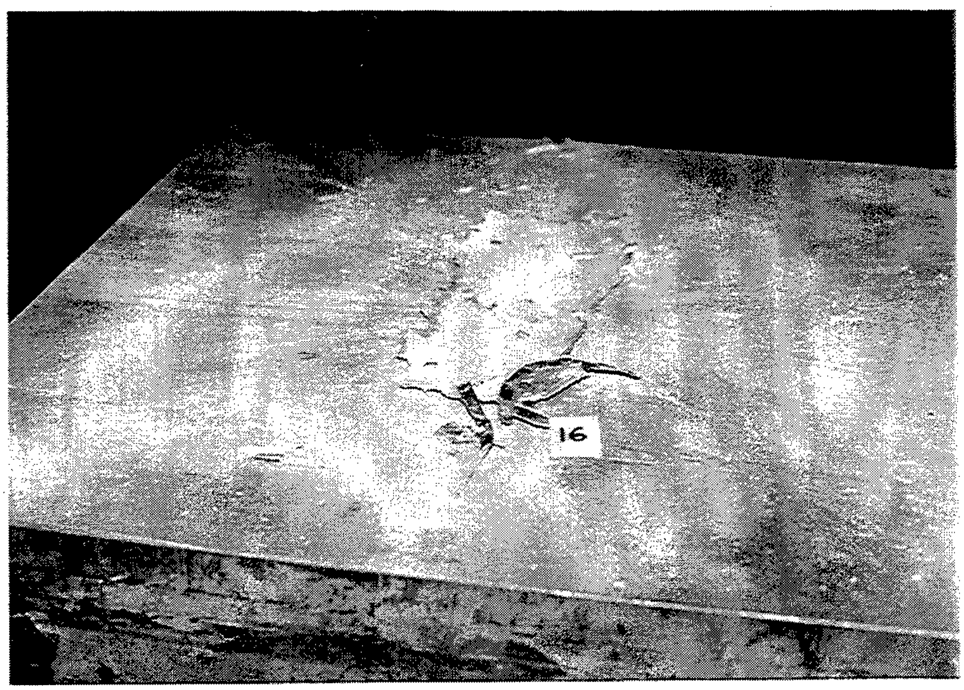


Figure 71
Debris from live M77 grenade test 16

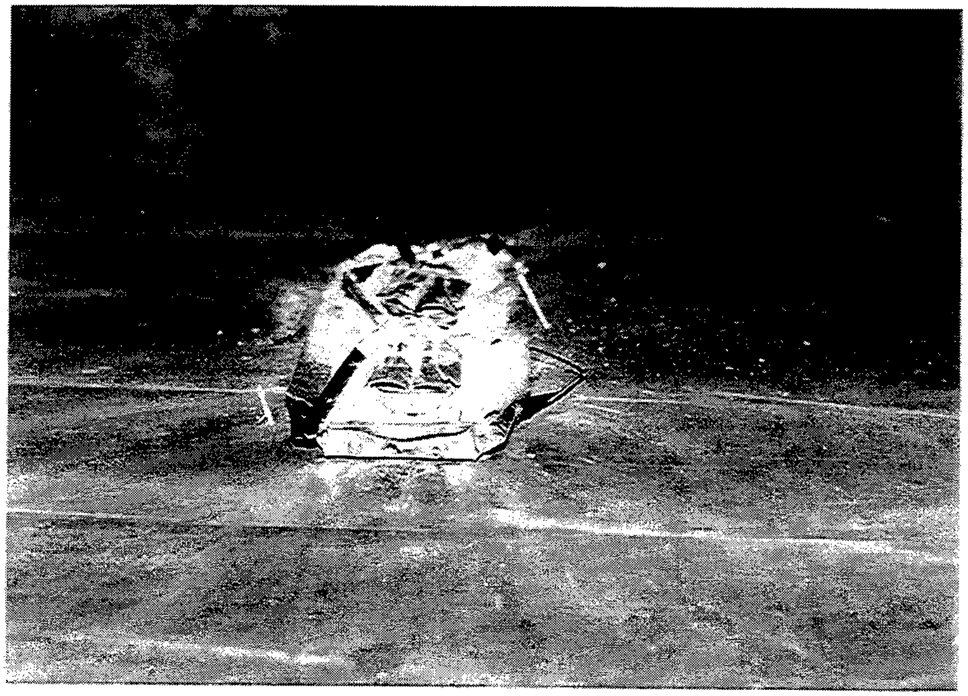


Figure 72
Debris from live M77 grenade test 18

Figure 73
Debris from live M77 grenade test 24

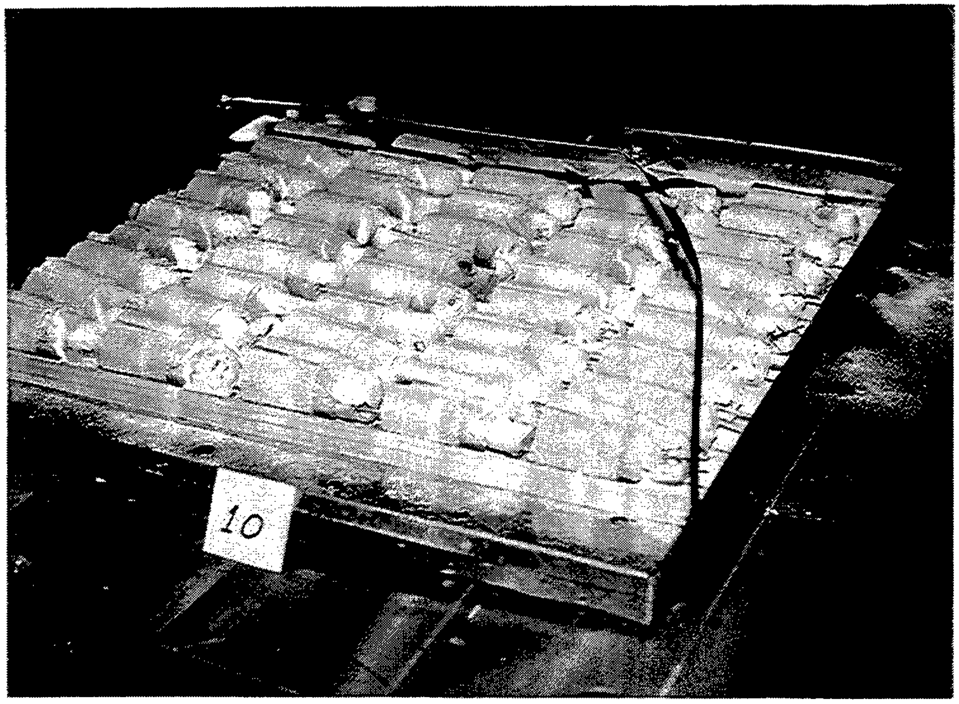


Figure 74
Debris from live M77 grenade test 10

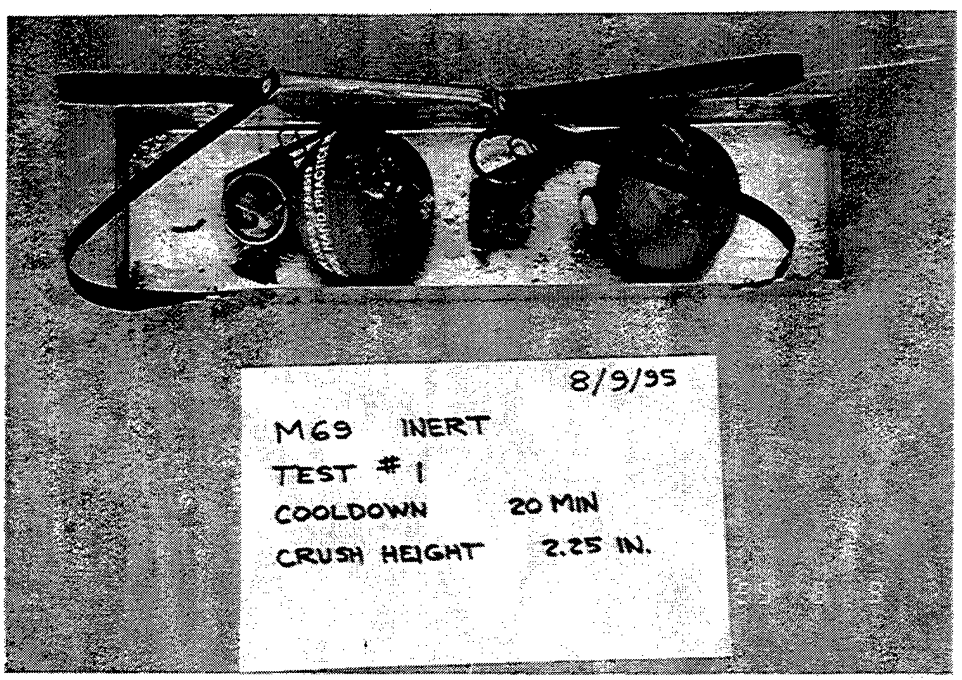


Figure 75
Debris from inert M69 hand grenade test 1

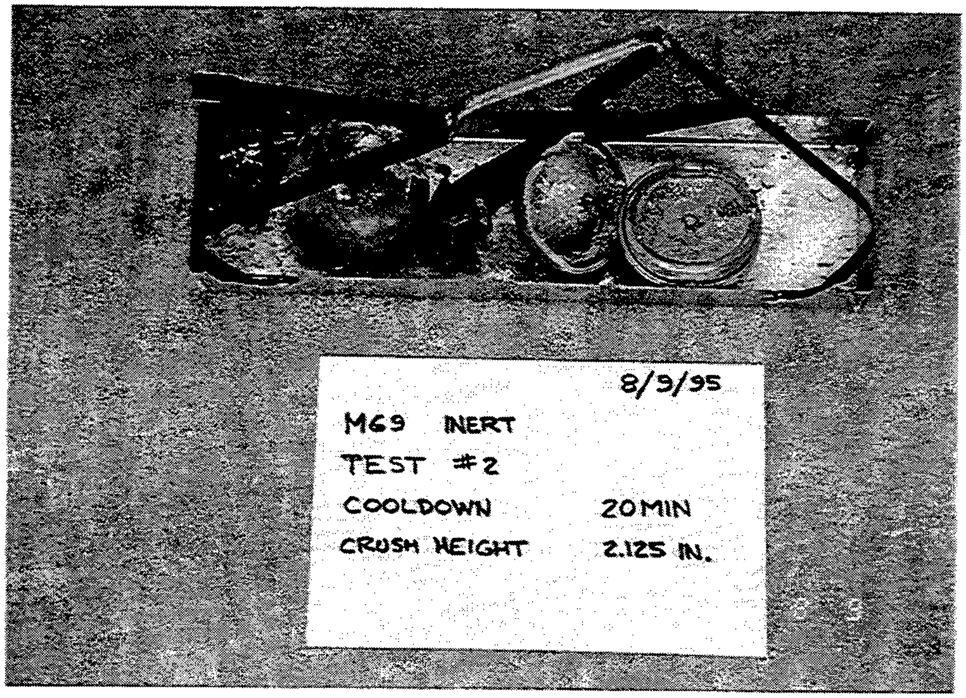


Figure 76
Debris from inert M69 hand grenade test 2

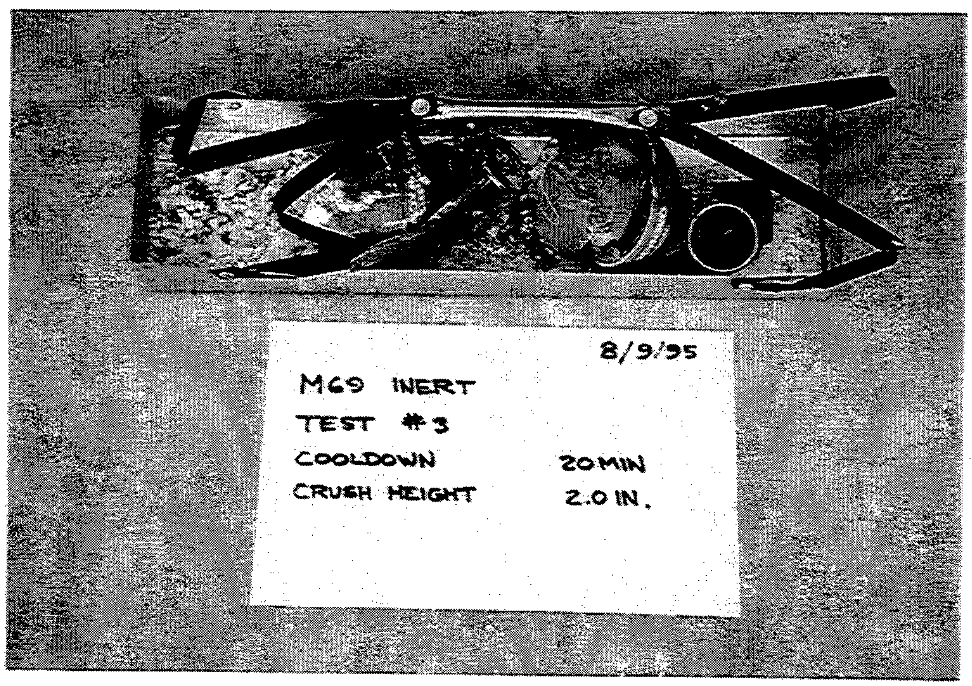


Figure 77
Debris from inert M69 hand grenade test 3

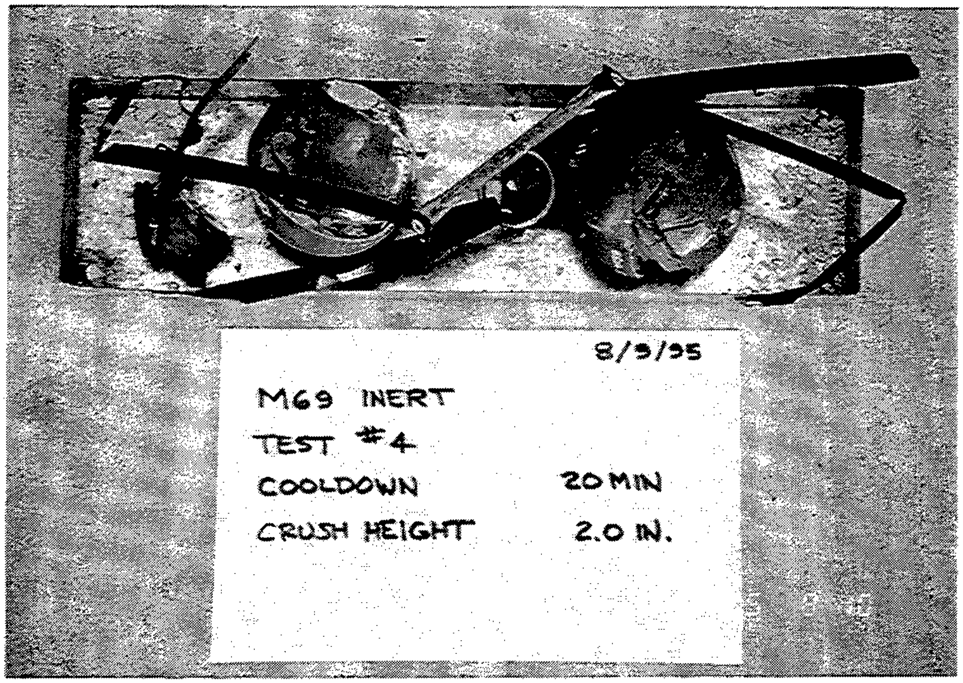


Figure 78
Debris from inert M69 hand grenade test 4

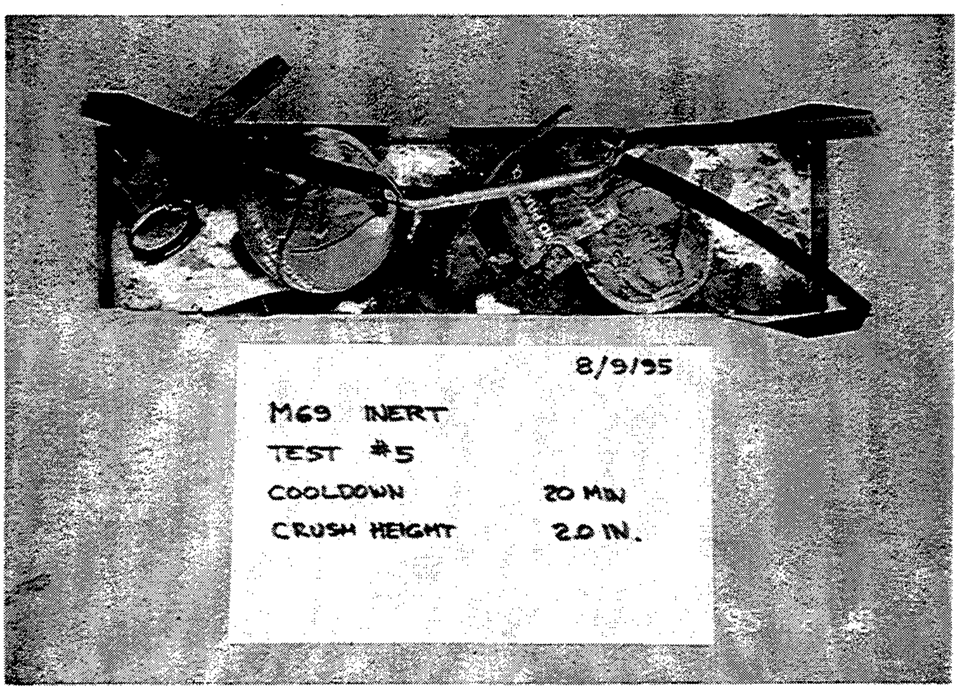


Figure 79
Debris from inert M69 hand grenade test 5

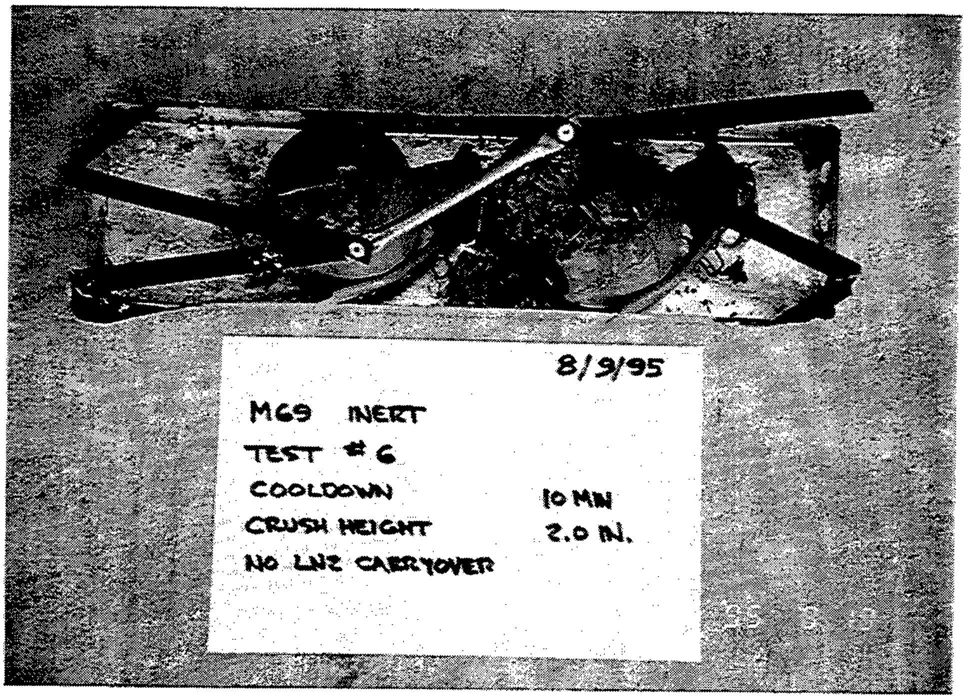


Figure 80
Debris from inert M69 hand grenade test 6

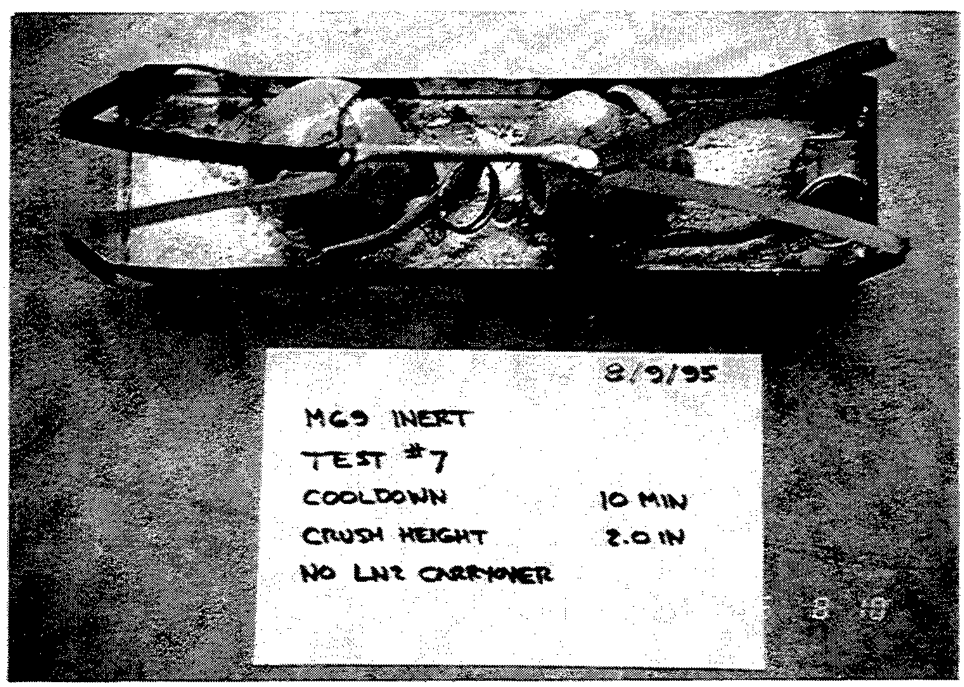


Figure 81
Debris from inert M69 hand grenade test 7

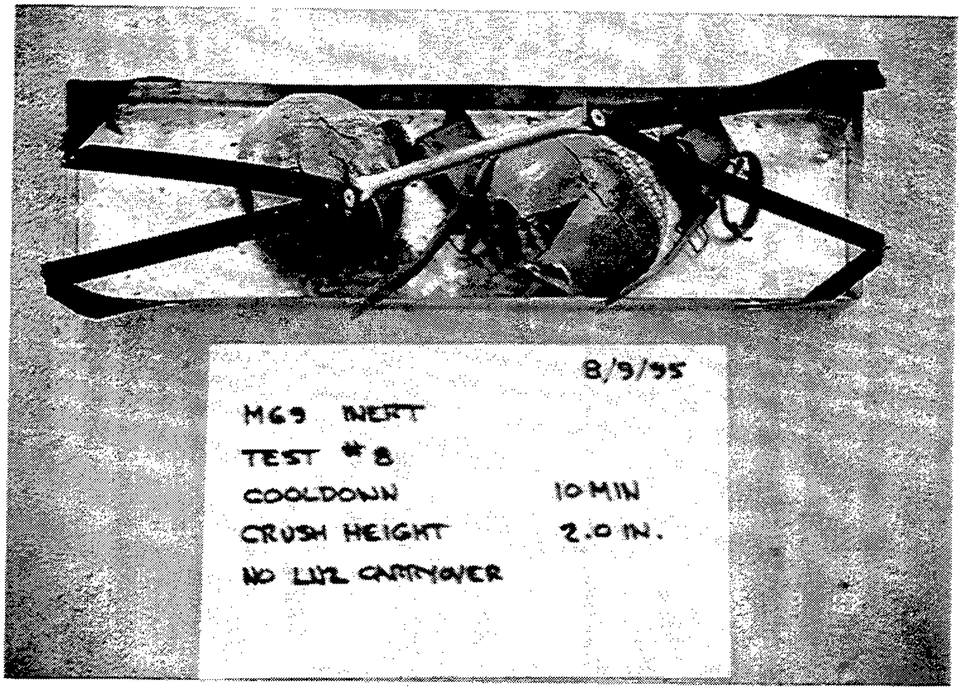


Figure 82
Debris from inert M69 hand grenade test 8

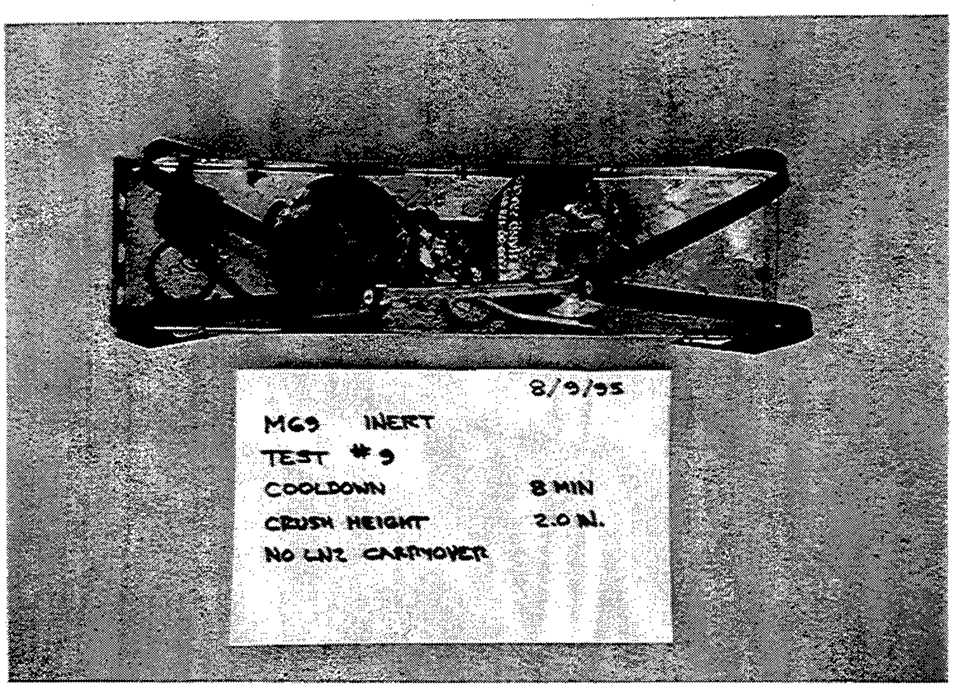


Figure 83
Debris from inert M69 hand grenade test 9

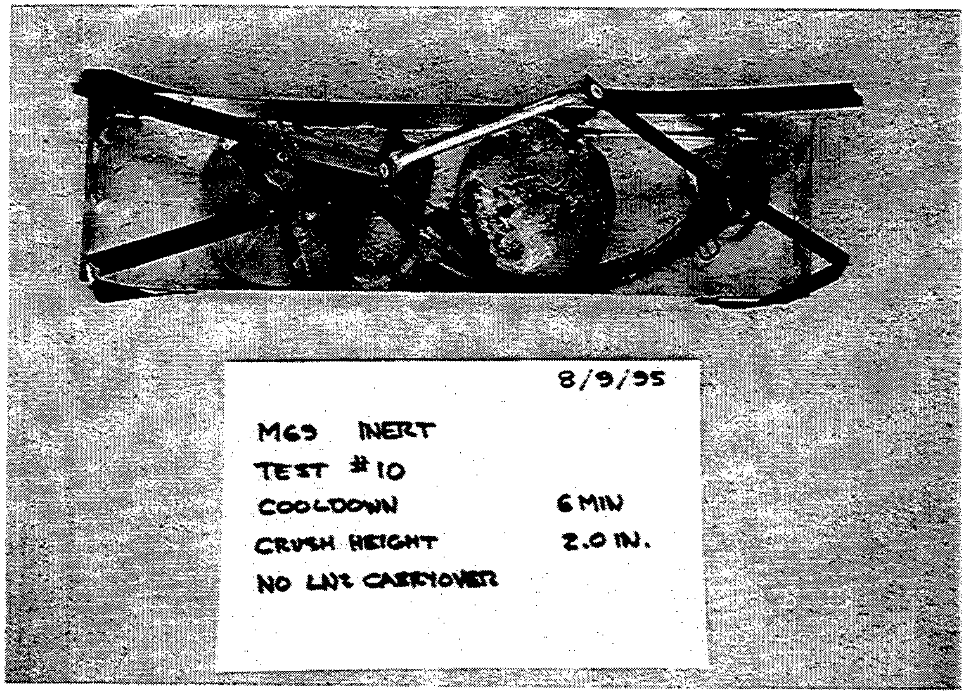


Figure 84
Debris from inert M69 hand grenade test 10

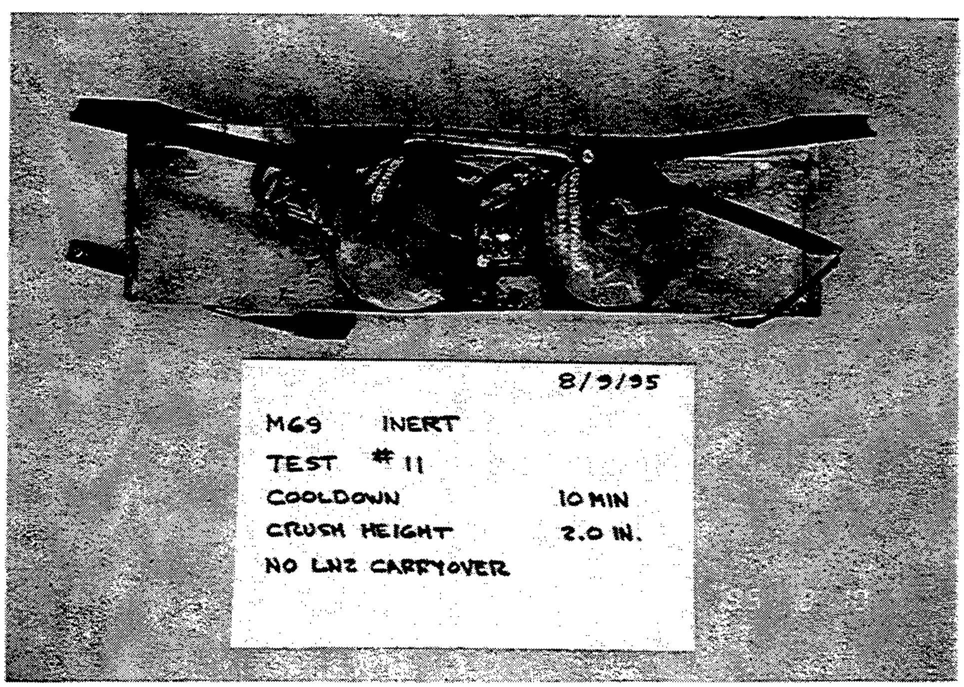


Figure 85
Debris from inert M69 hand grenade test 11

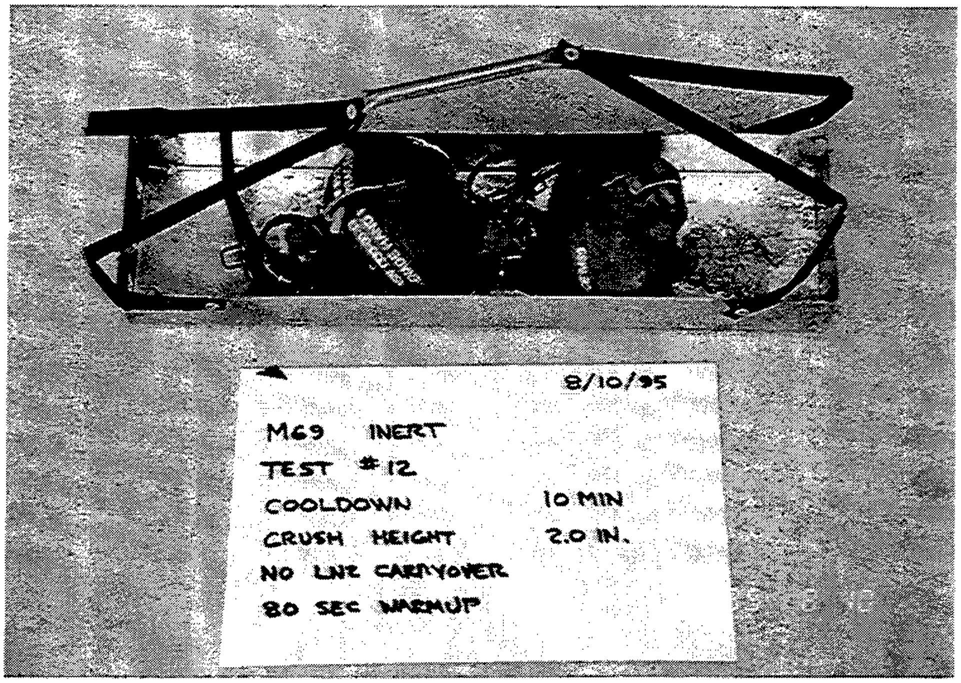


Figure 86
Debris from inert M69 hand grenade test 12

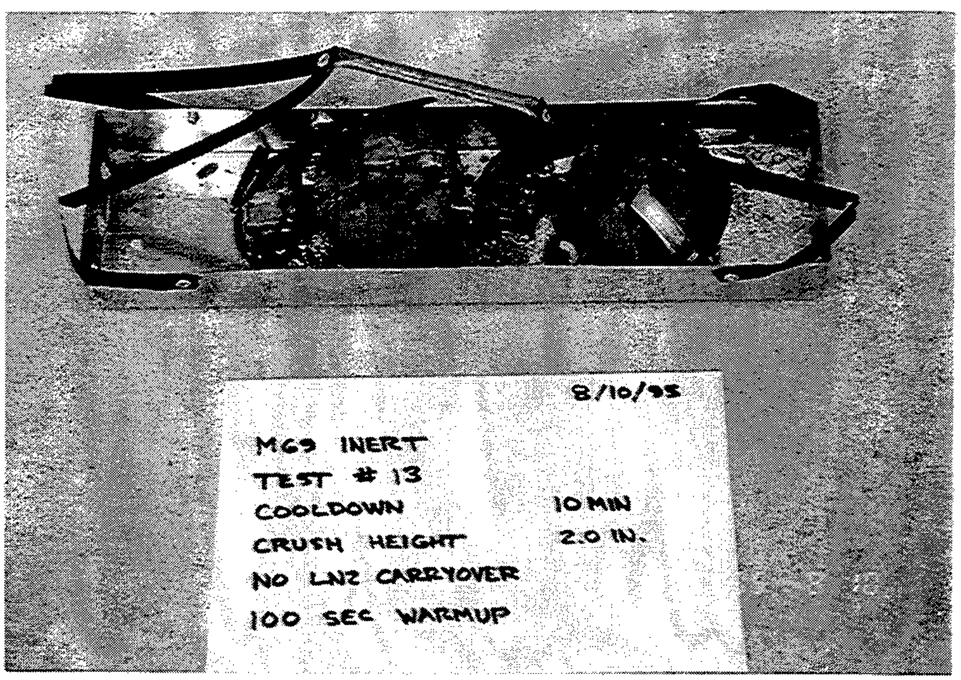


Figure 87
Debris from inert M69 hand grenade test 13

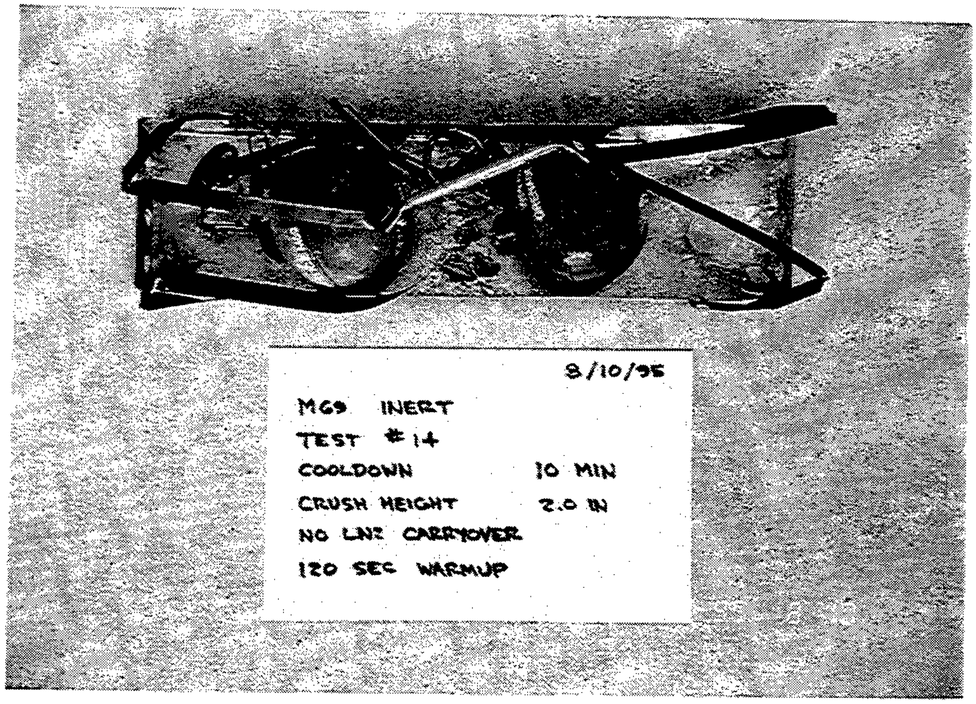


Figure 88
Debris from inert M69 hand grenade test 14

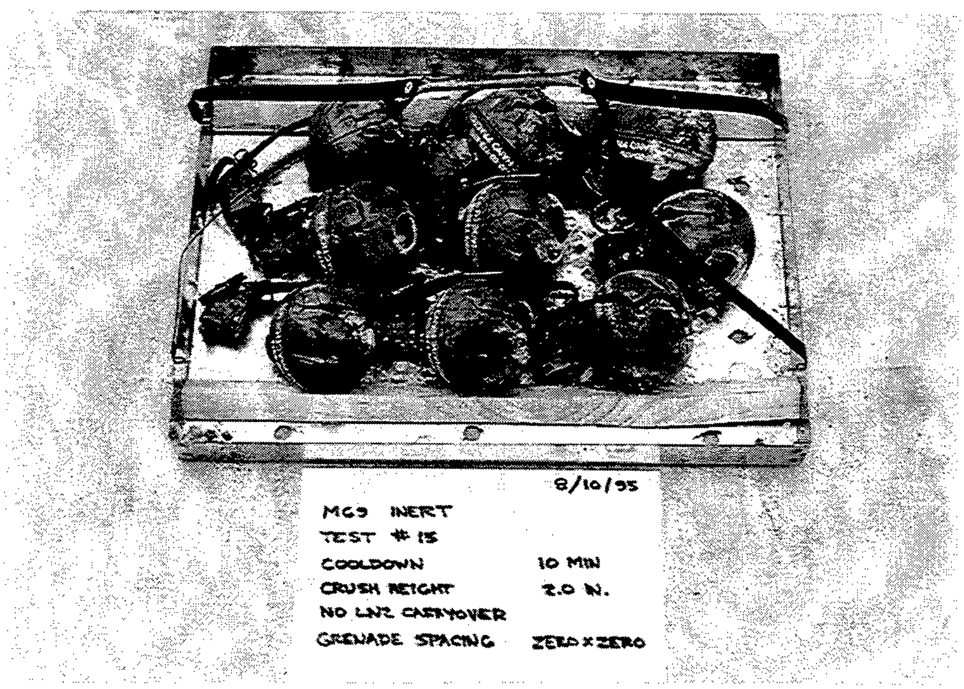


Figure 89
Debris from inert M69 hand grenade test 15

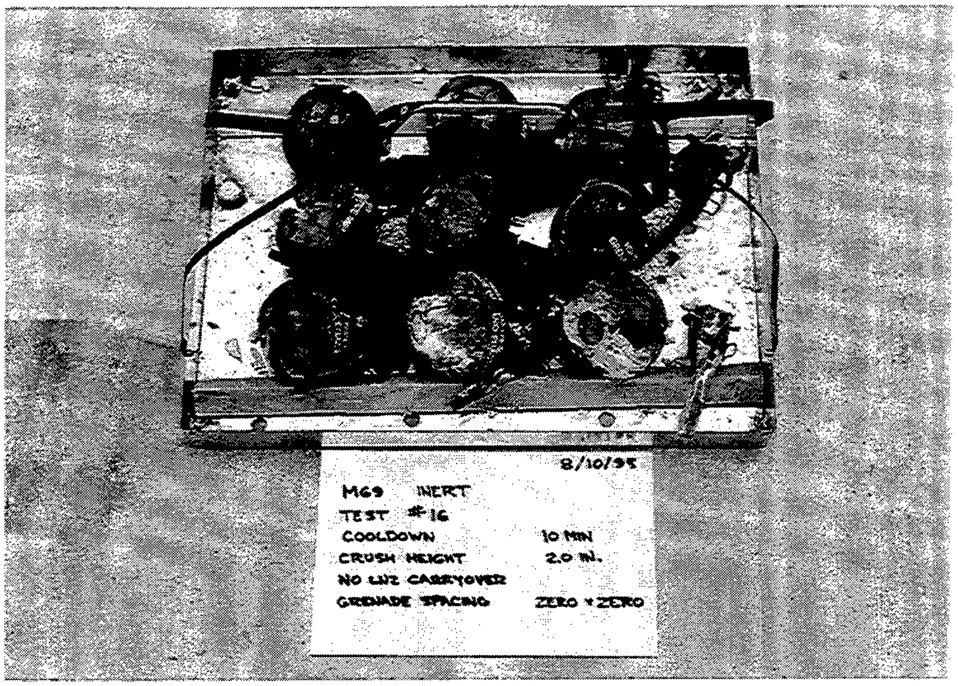


Figure 90
Debris from inert M69 hand grenade test 16

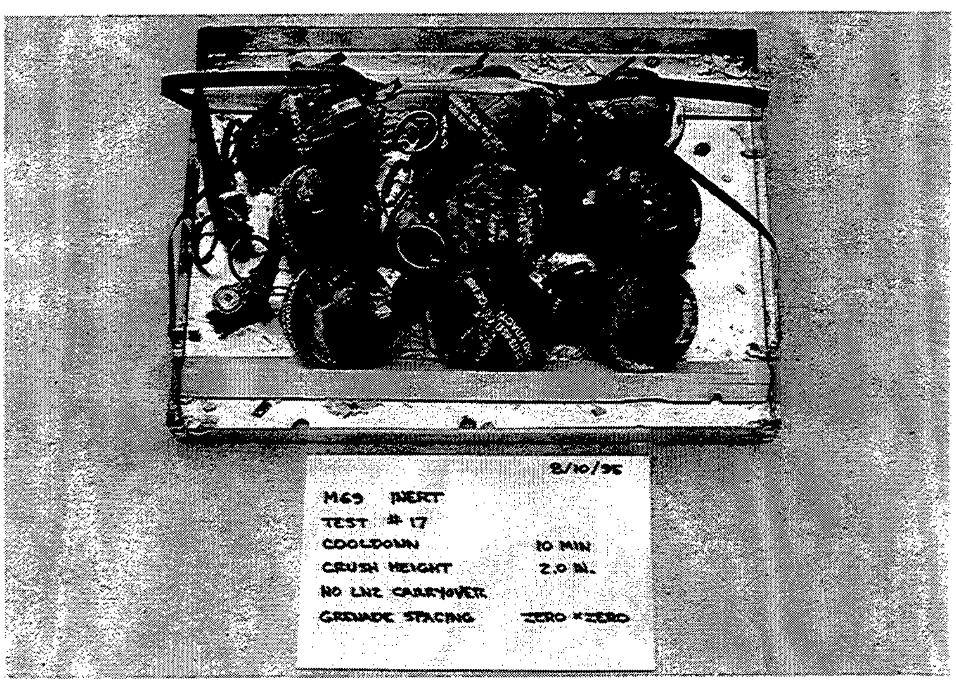


Figure 91
Debris from inert M69 hand grenade test 17

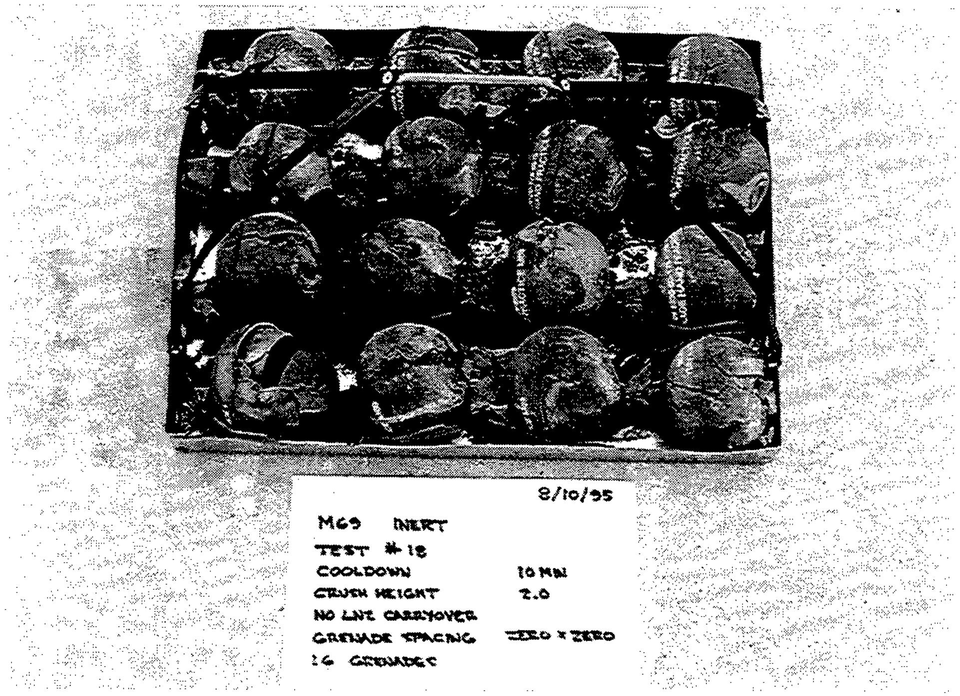


Figure 92
Debris from inert M69 hand grenade test 18

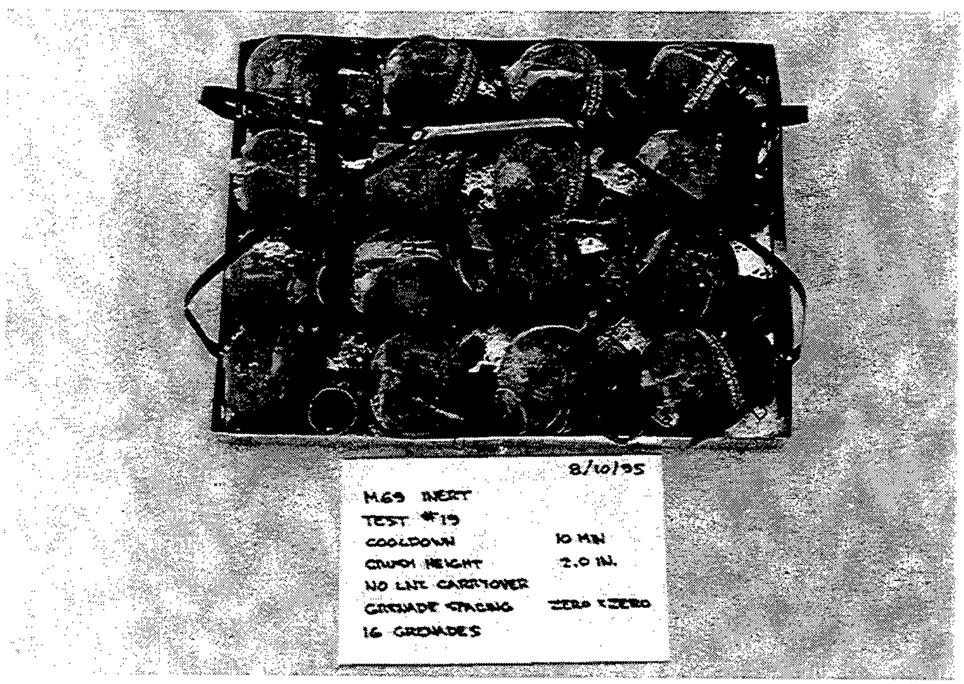


Figure 93
Debris from inert M69 hand grenade test 19

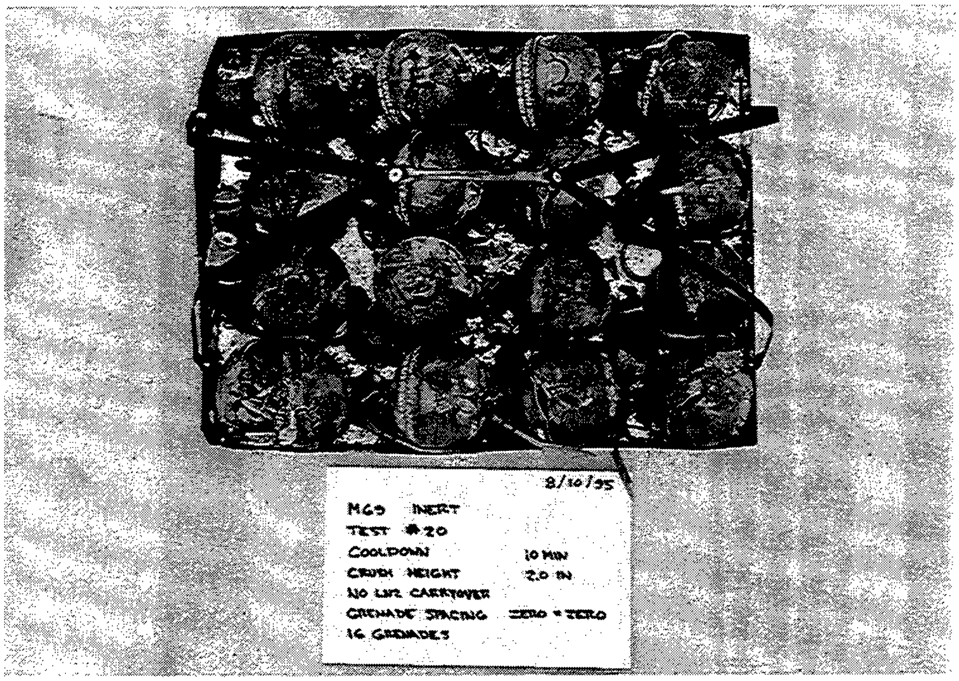


Figure 94
Debris from inert M69 hand grenade test 20

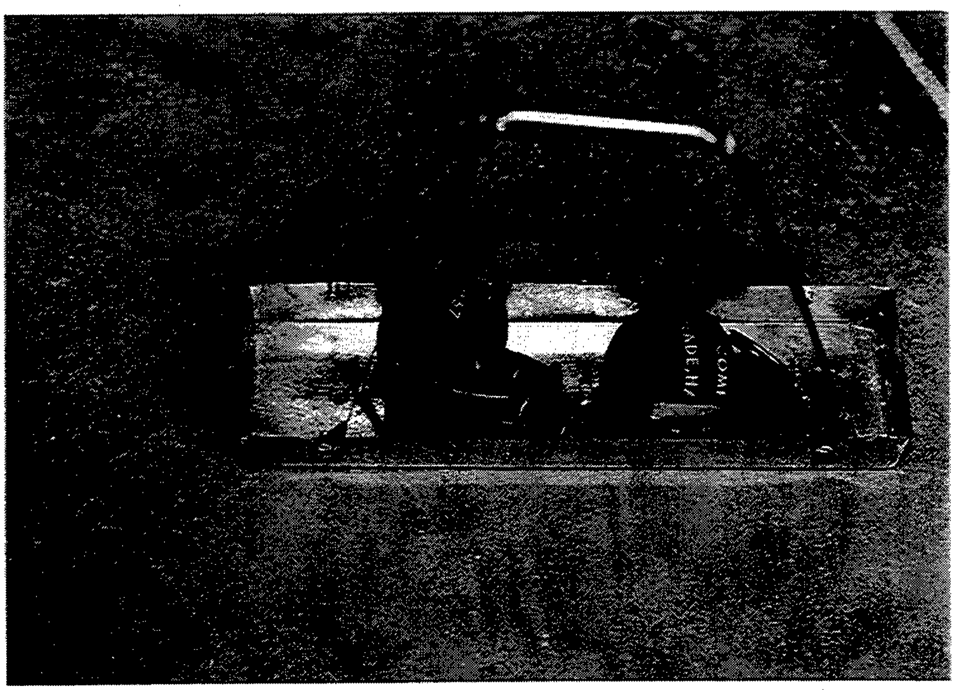


Figure 95
Loaded munitions handling basket with two M67 hand grenades

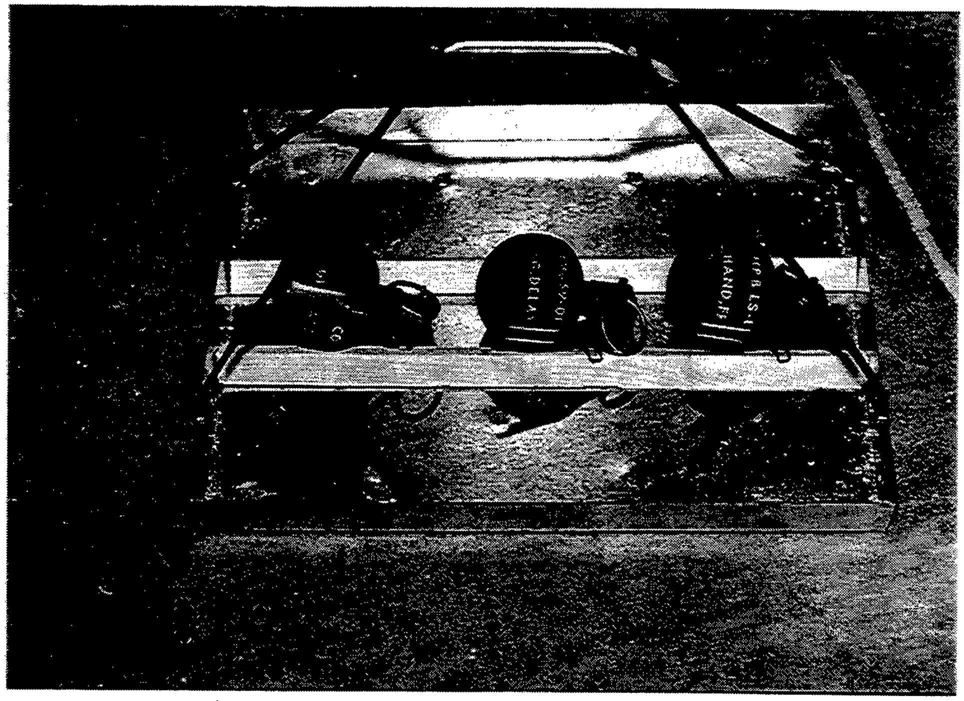


Figure 96
Loaded munitions handling basket with three M67 hand grenades

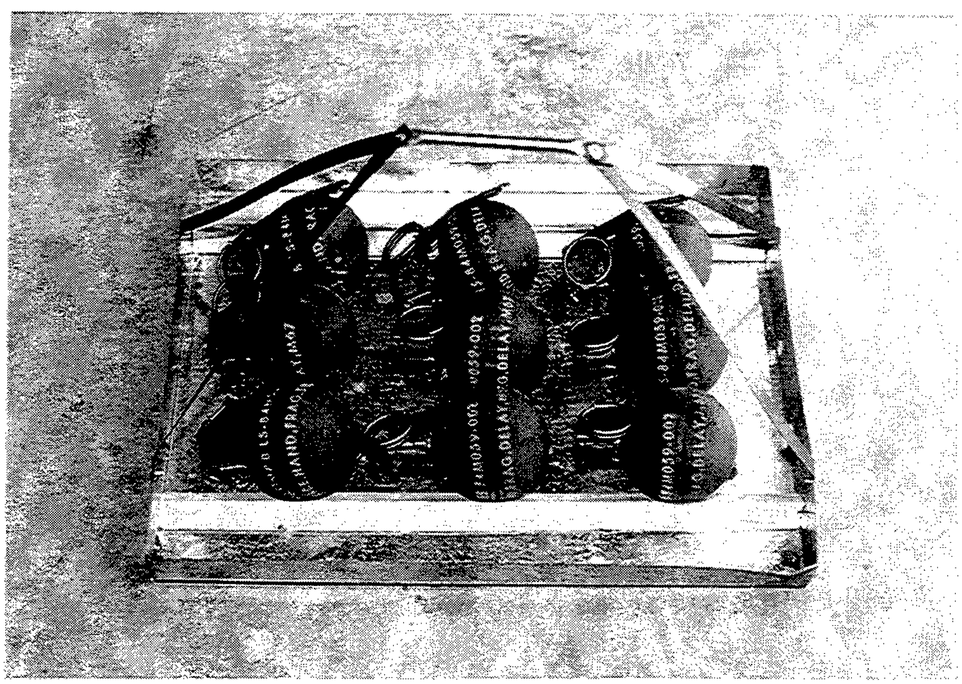


Figure 97
Loaded munitions handling basket with nine M67 hand grenades

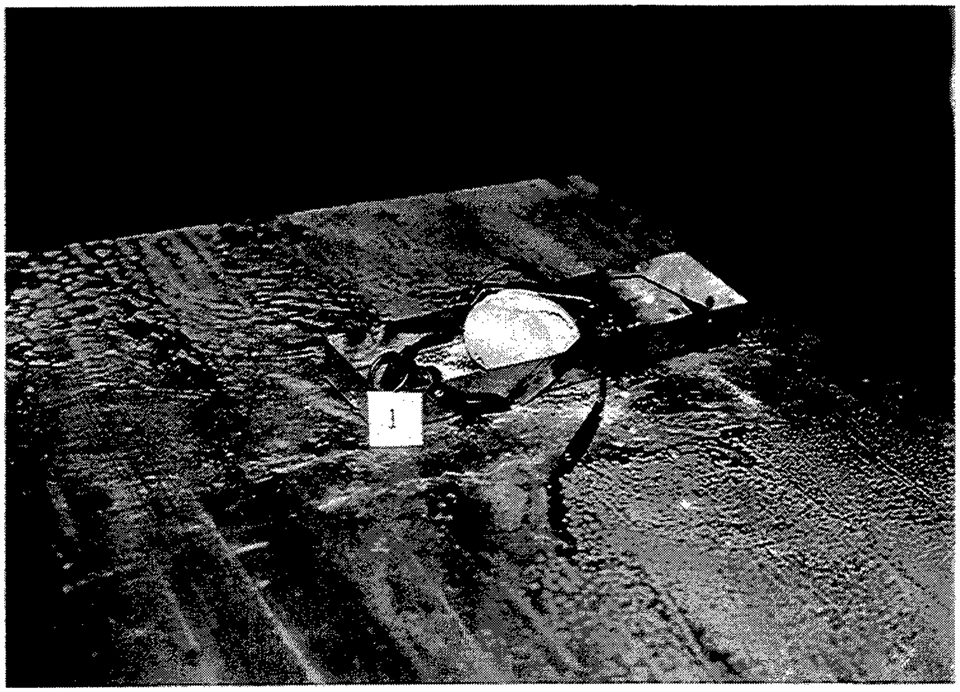


Figure 98
Debris from live M67 hand grenade test 1

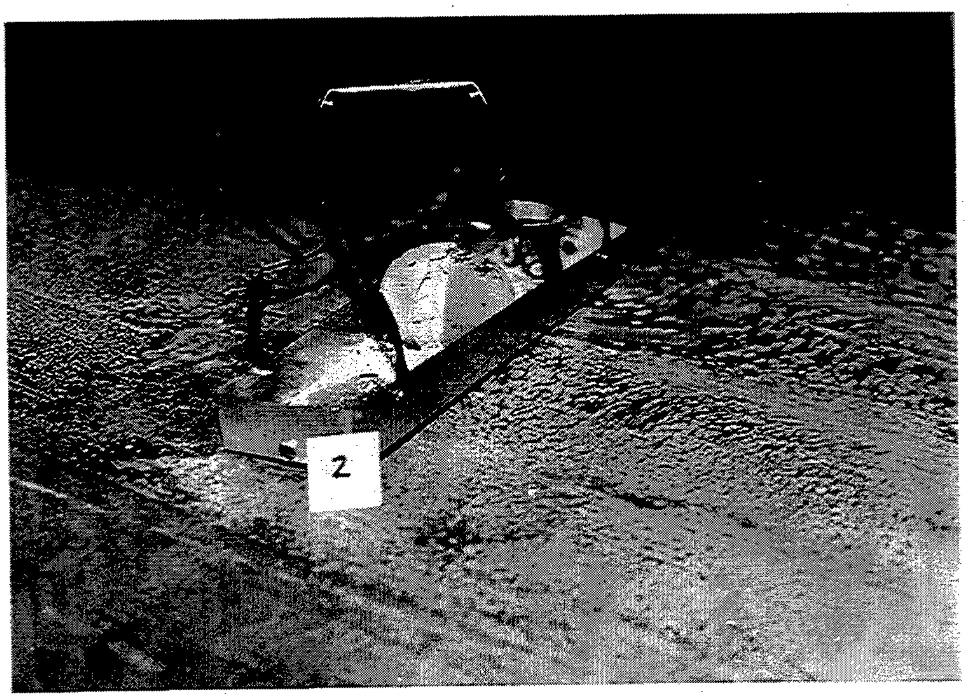


Figure 99
Debris from live M67 hand grenade test 2

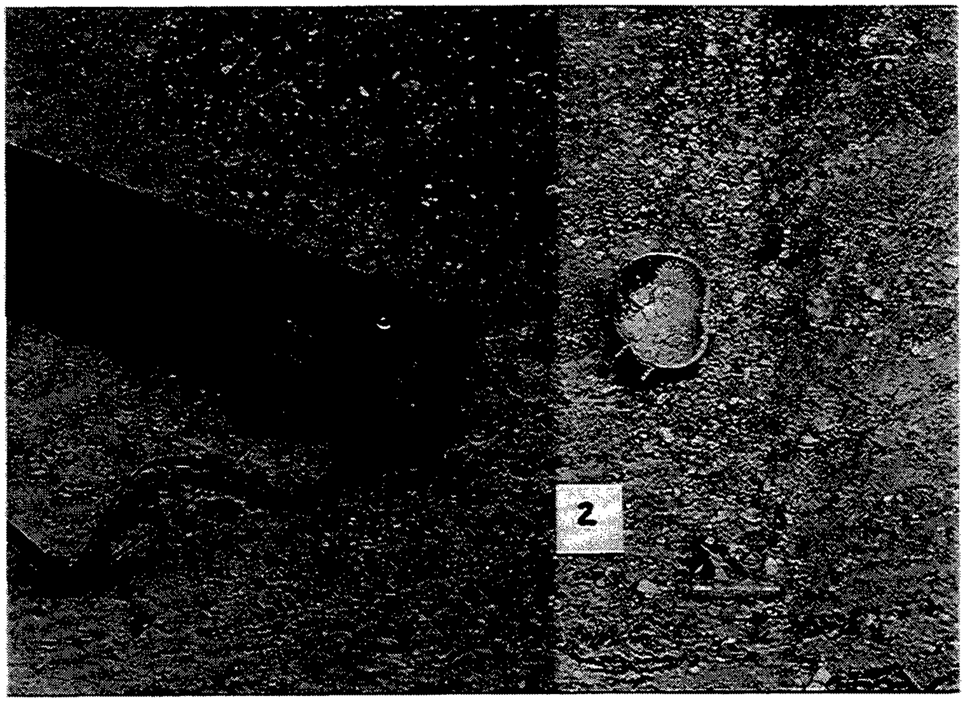


Figure 100
Debris from live M67 hand grenade test 2

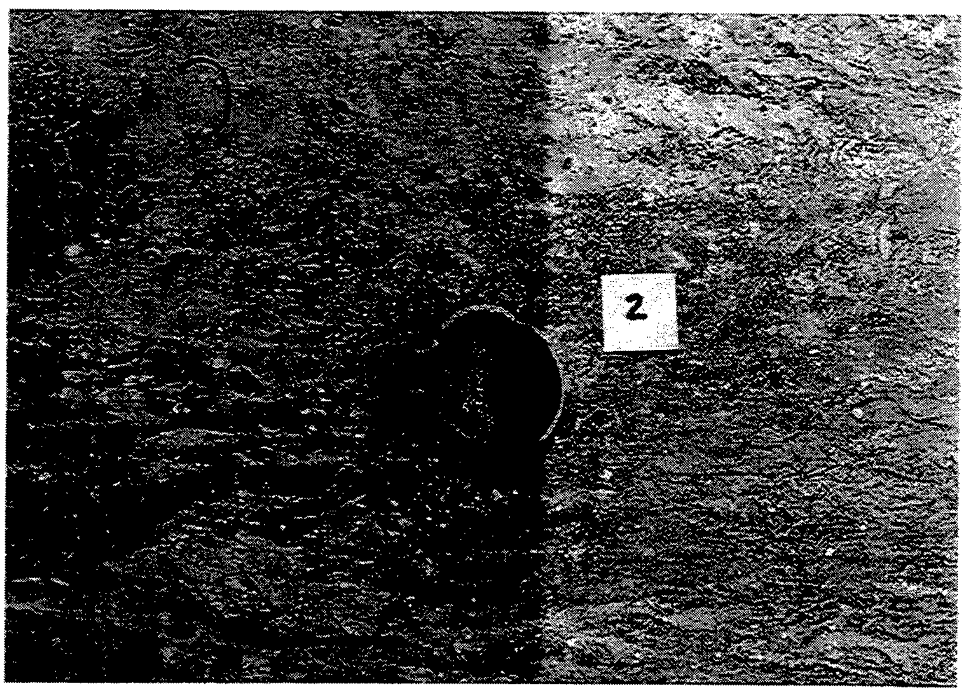


Figure 101
Debris from live M67 hand grenade test 2

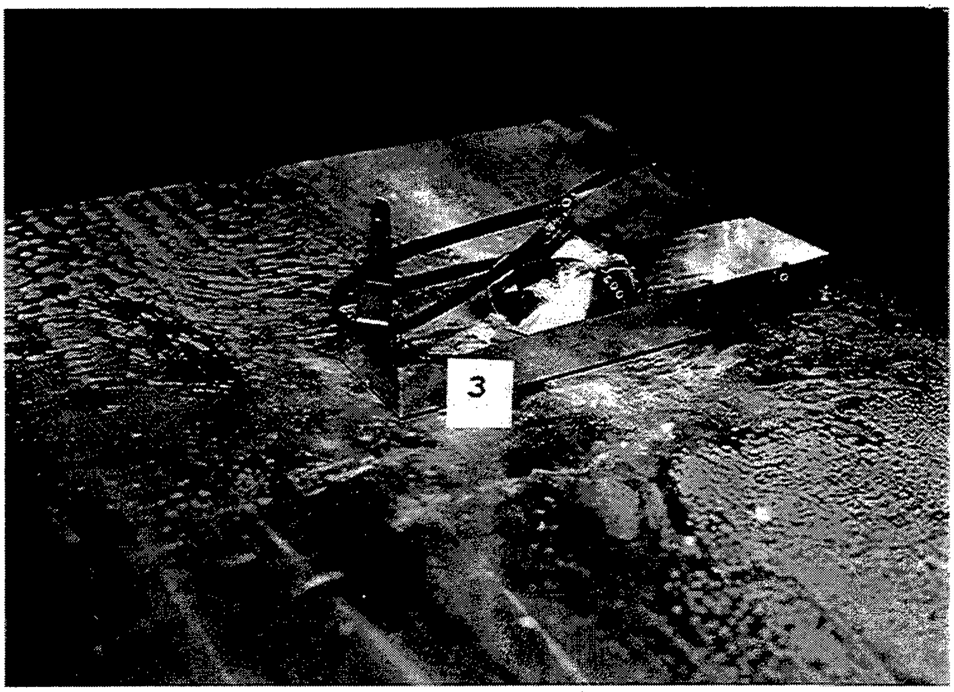


Figure 102
Debris from live M67 hand grenade test 3

Figure 103
Debris from live M67 hand grenade test 3

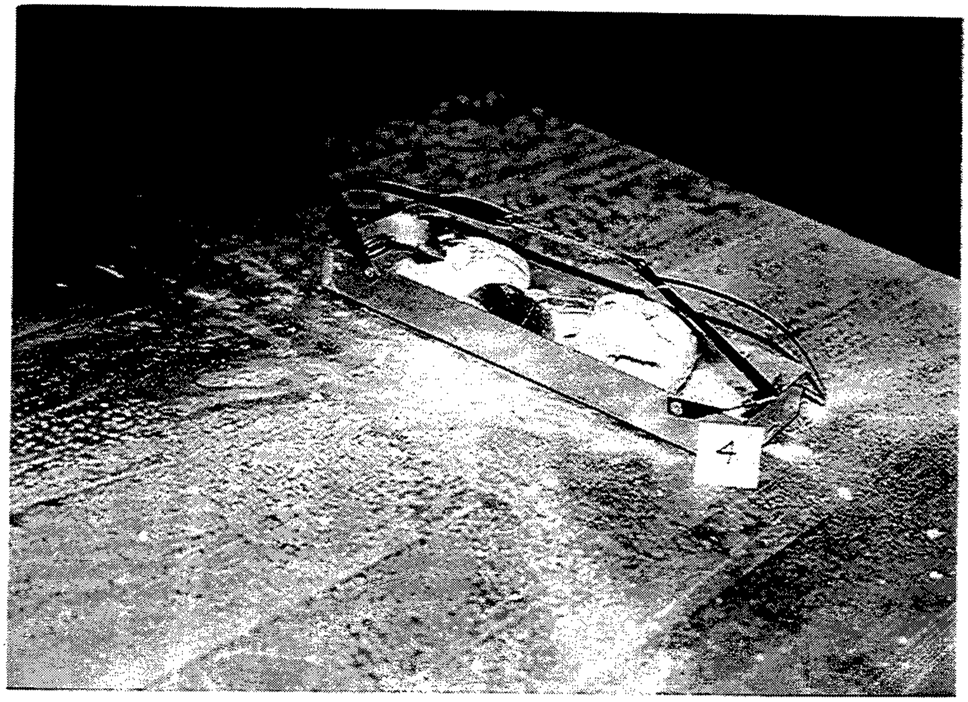


Figure 104
Debris from live M67 hand grenade test 4

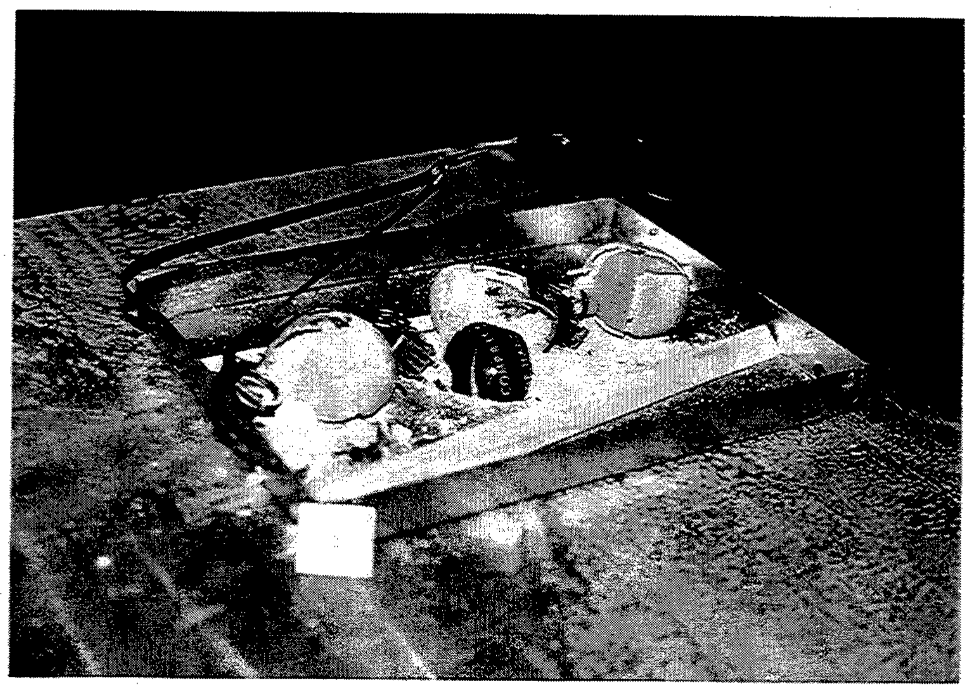


Figure 105
Debris from live M67 hand grenade test 5

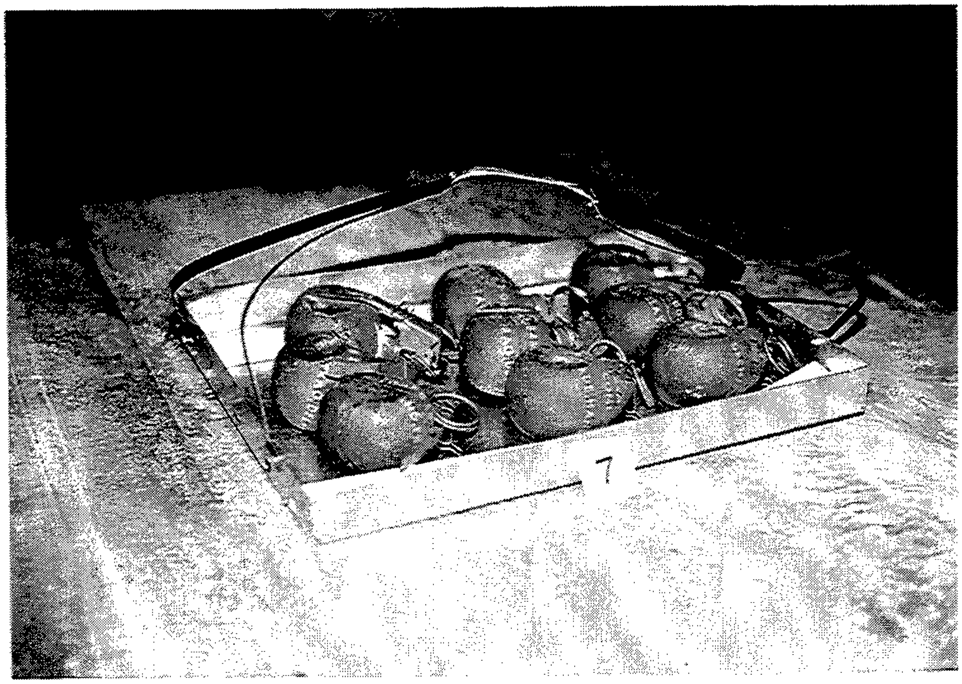


Figure 106
Debris from live M67 hand grenade test 7

Figure 107
Debris from live M67 hand grenade test 4

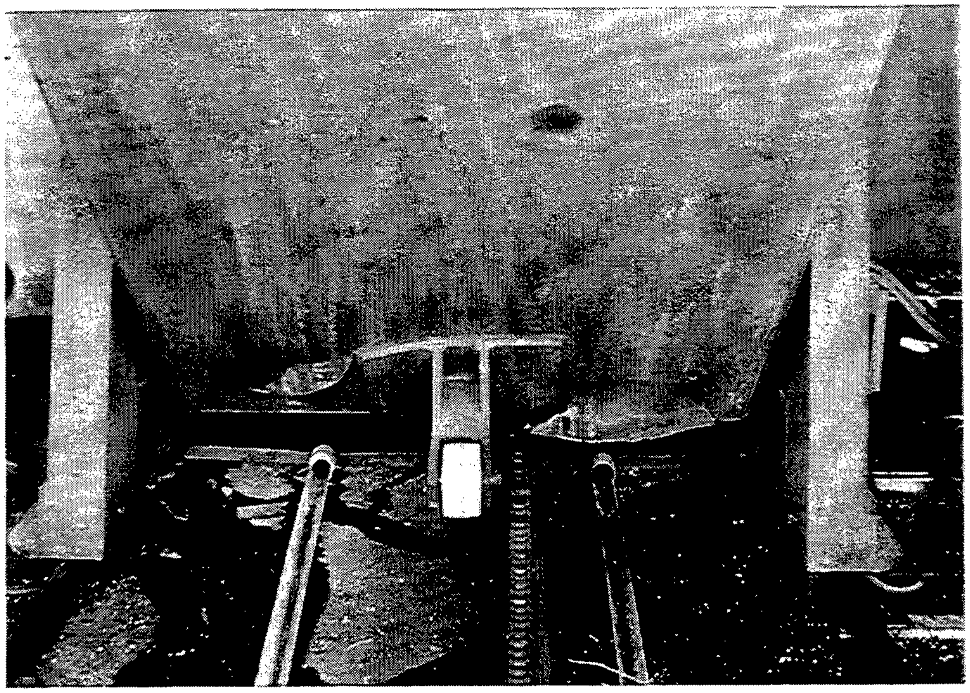


Figure 108
Fragment cart explosion damage

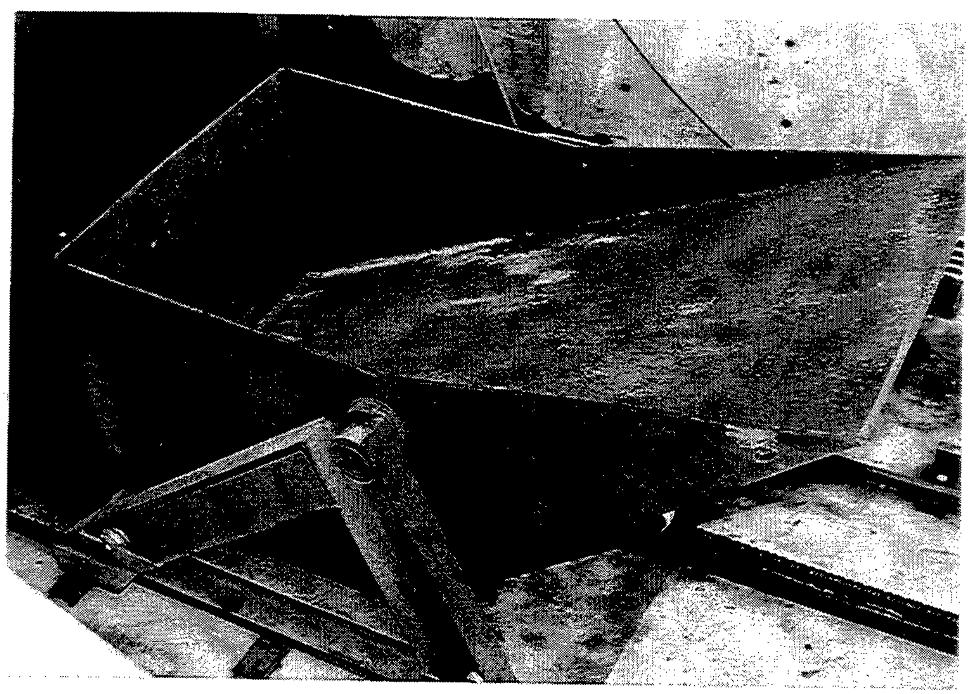


Figure 109
Modified fragment cart bottom

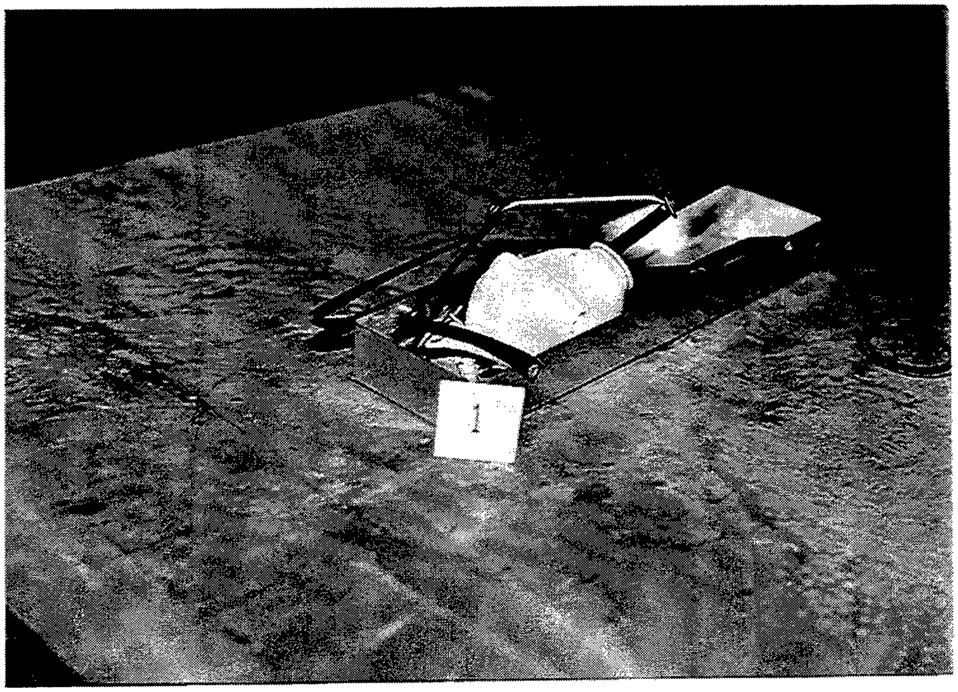


Figure 110
Debris from live M61 hand grenade test 1

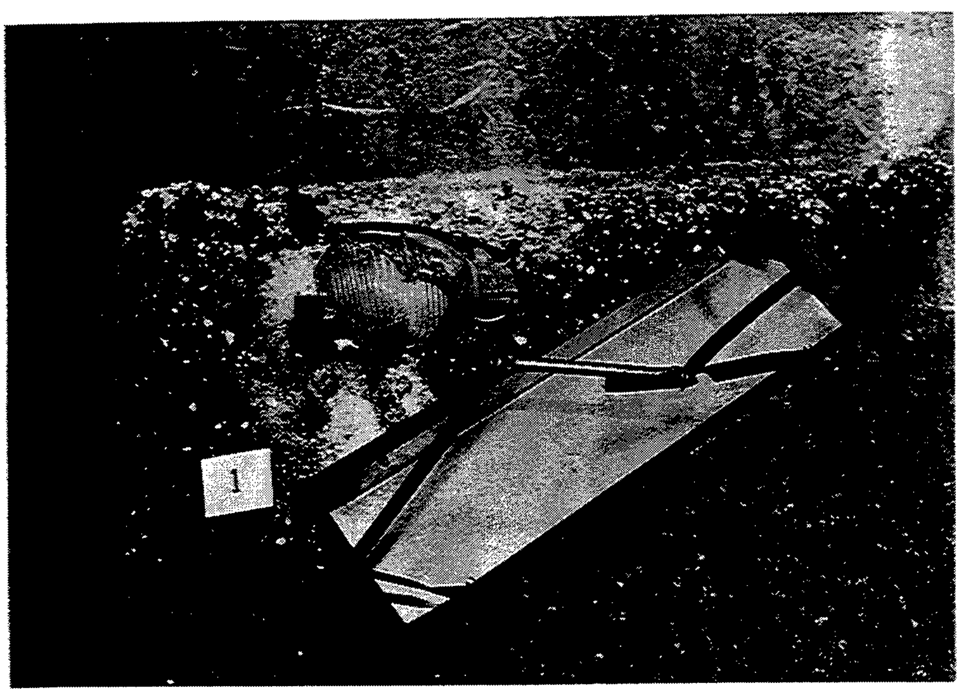


Figure 111
Debris from live M61 hand grenade test 1

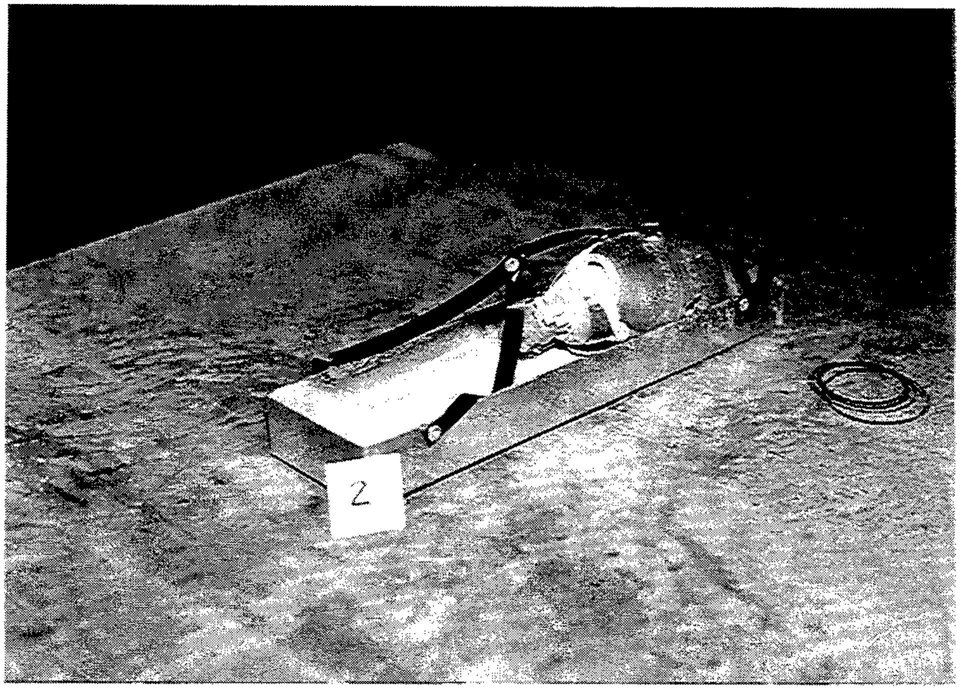


Figure 112
Debris from live M61 hand grenade test 2

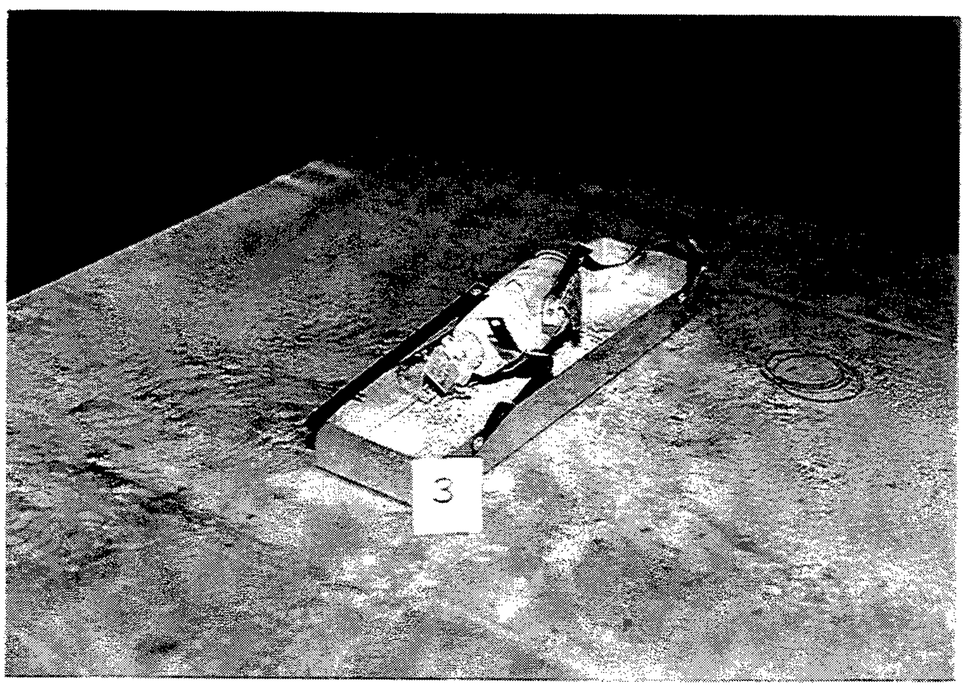


Figure 113
Debris from live M61 hand grenade test 3

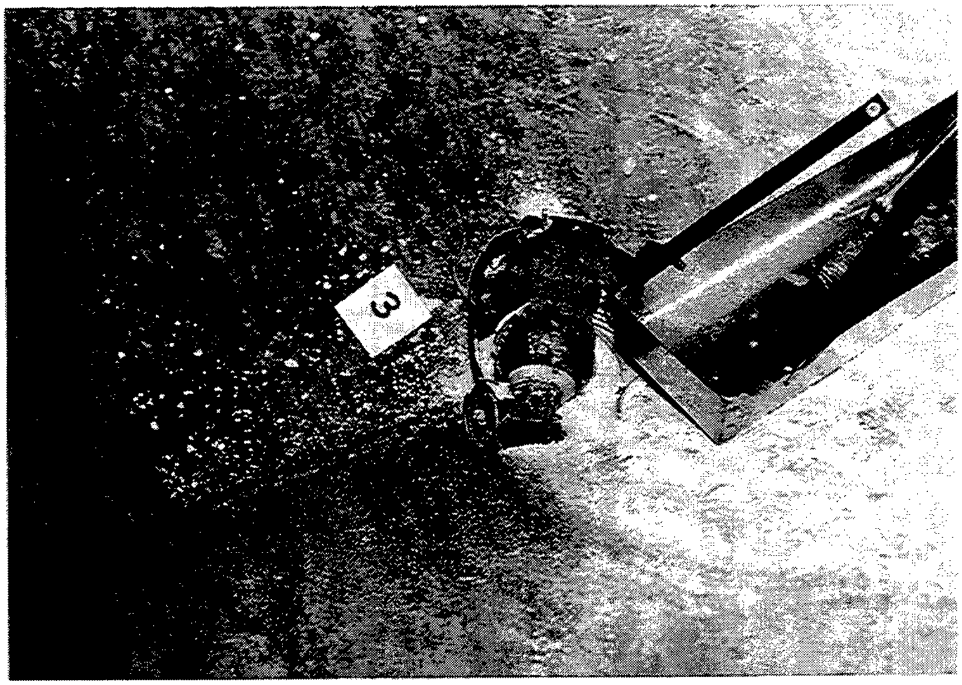


Figure 114
Debris from live M61 hand grenade test 3

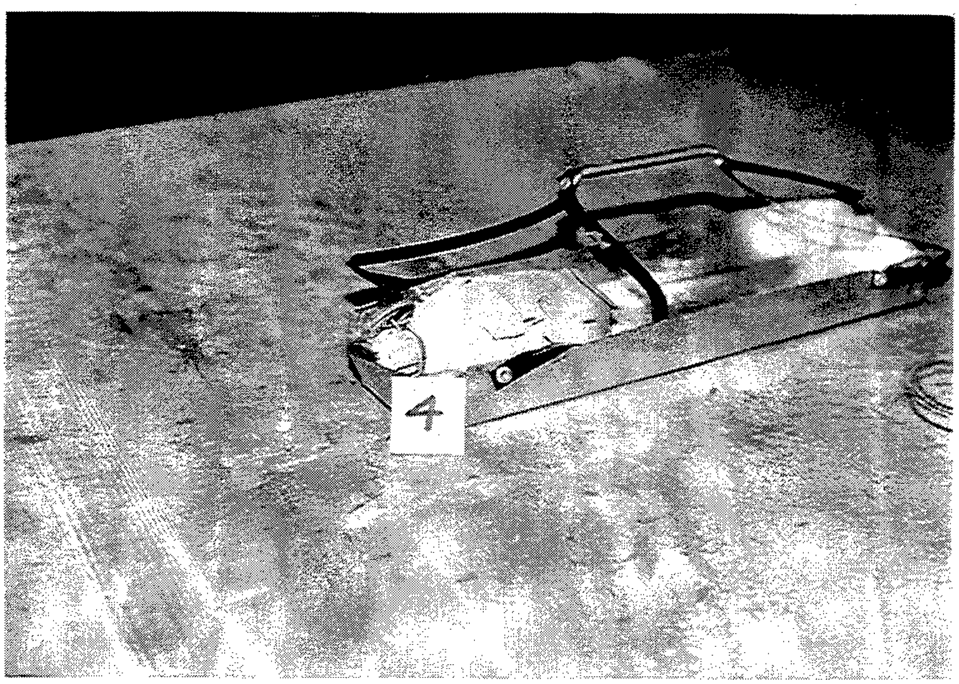


Figure 115
Debris from live M61 hand grenade test 4

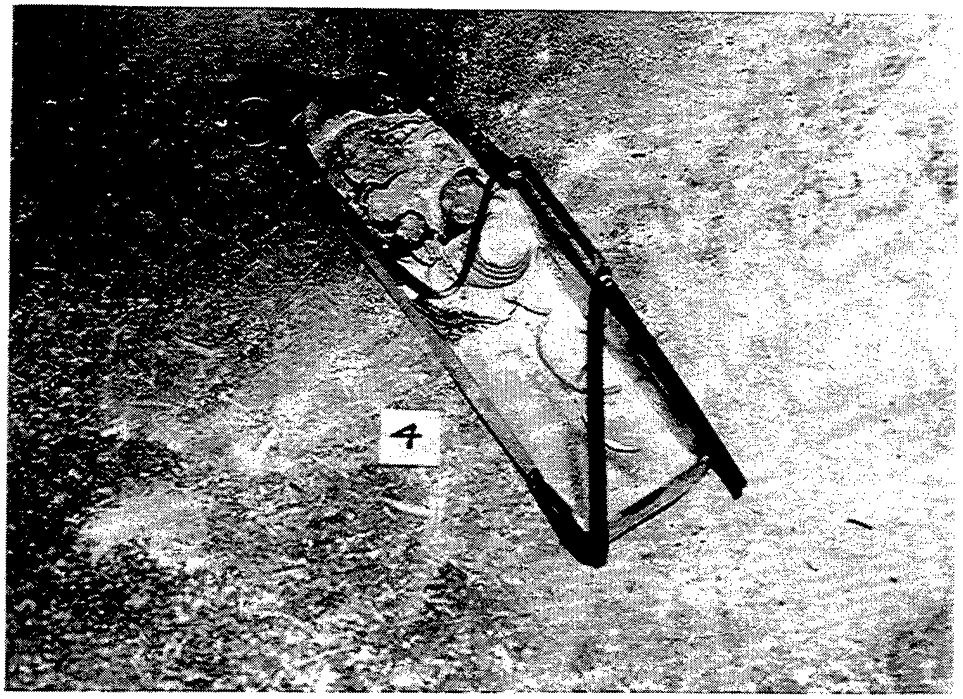


Figure 116
Debris from live M61 hand grenade test 4

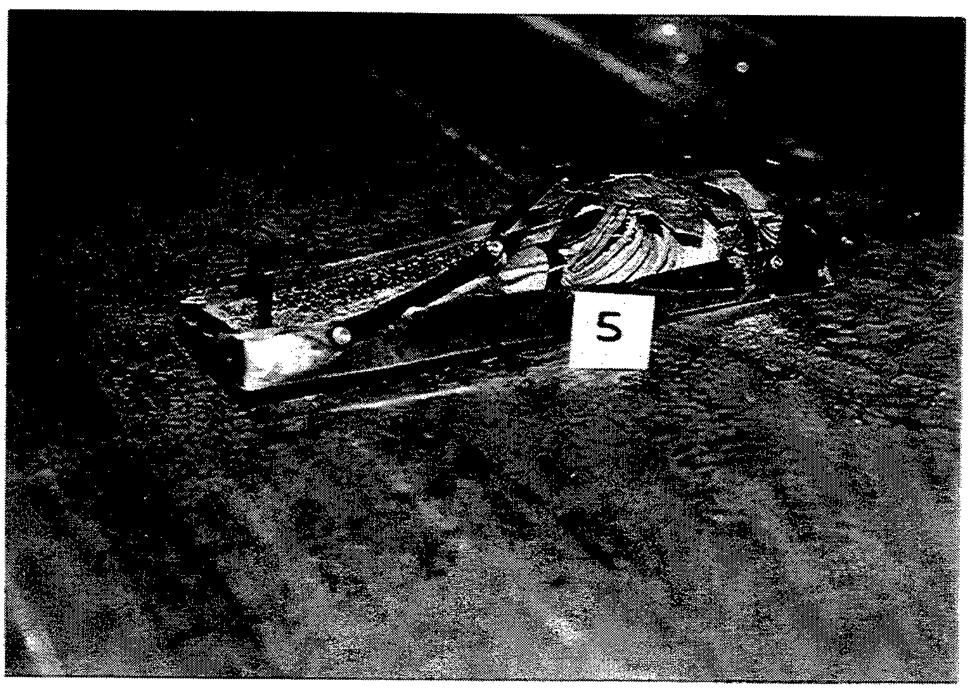


Figure 117
Debris from live M61 hand grenade test 5

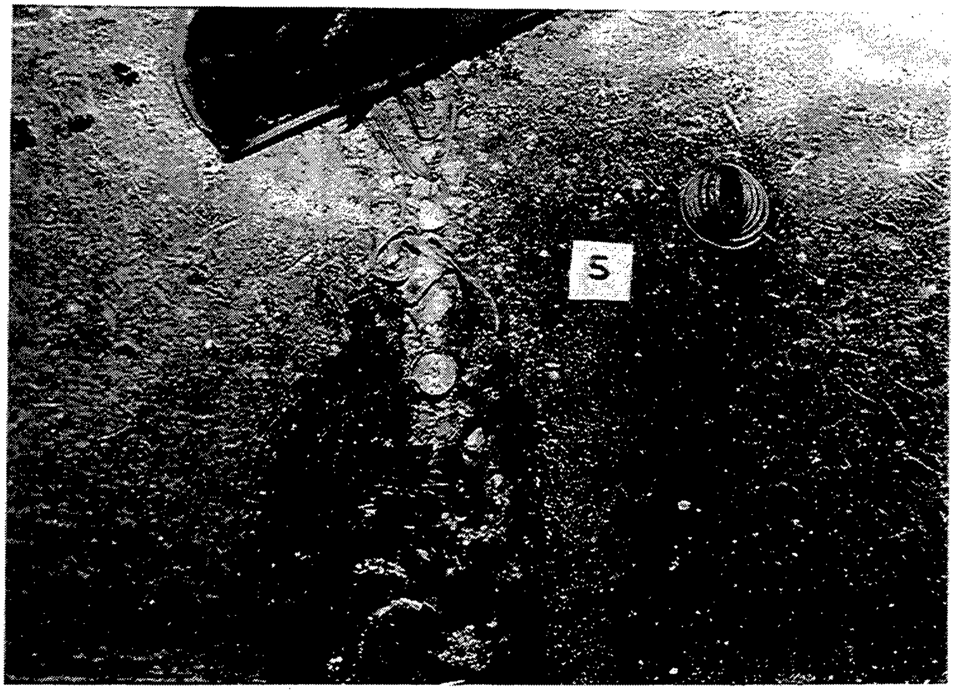


Figure 118
Debris from live M61 hand grenade test 5

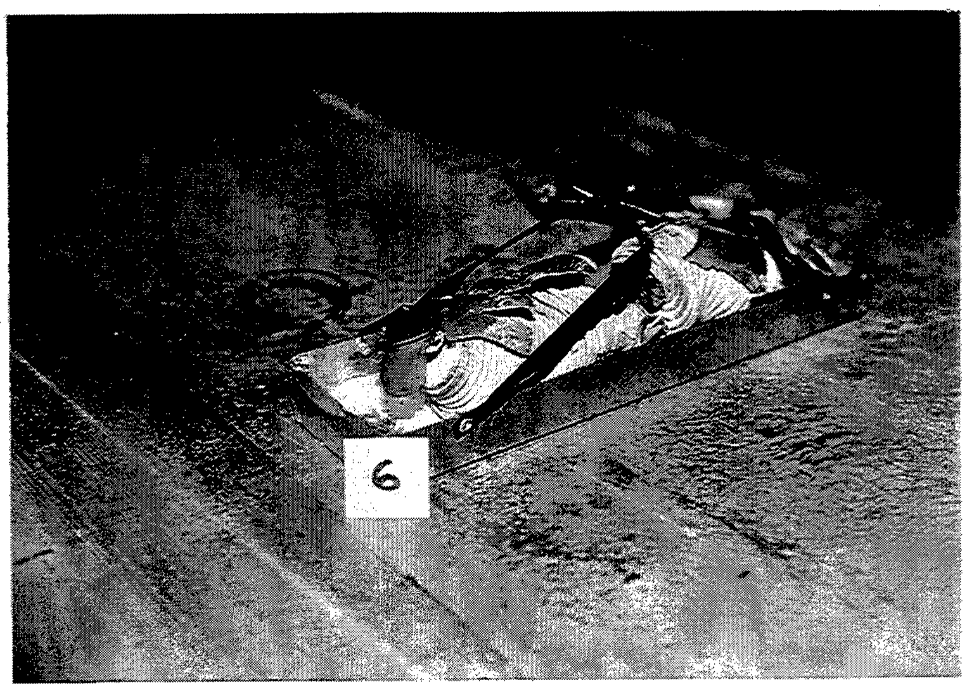


Figure 119
Debris from live M61 hand grenade test 6

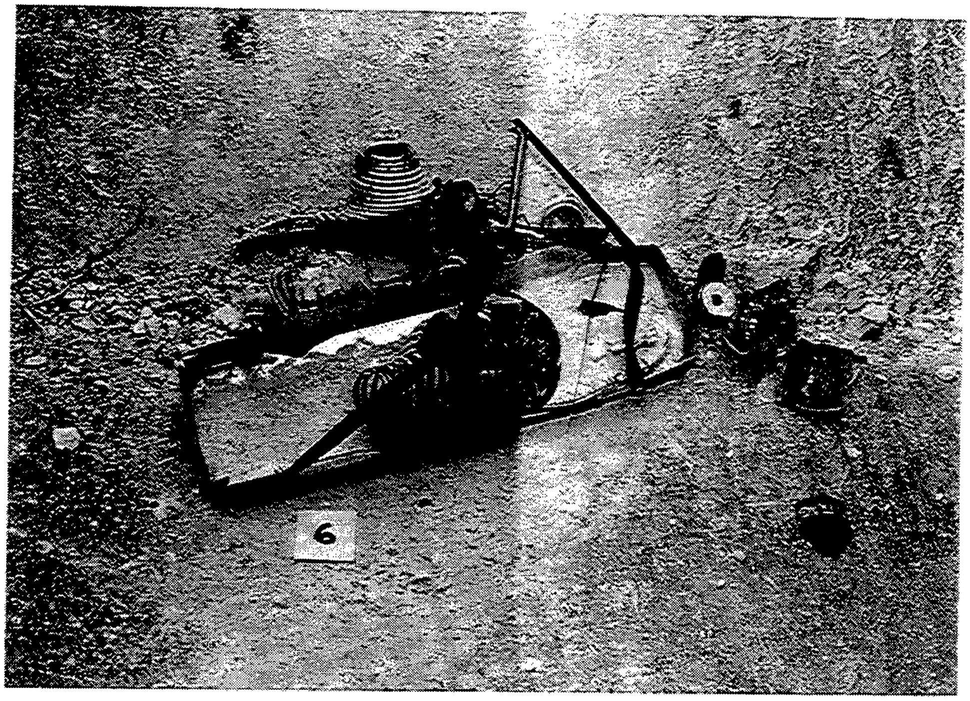


Figure 120
Debris from live M61 hand grenade test 6

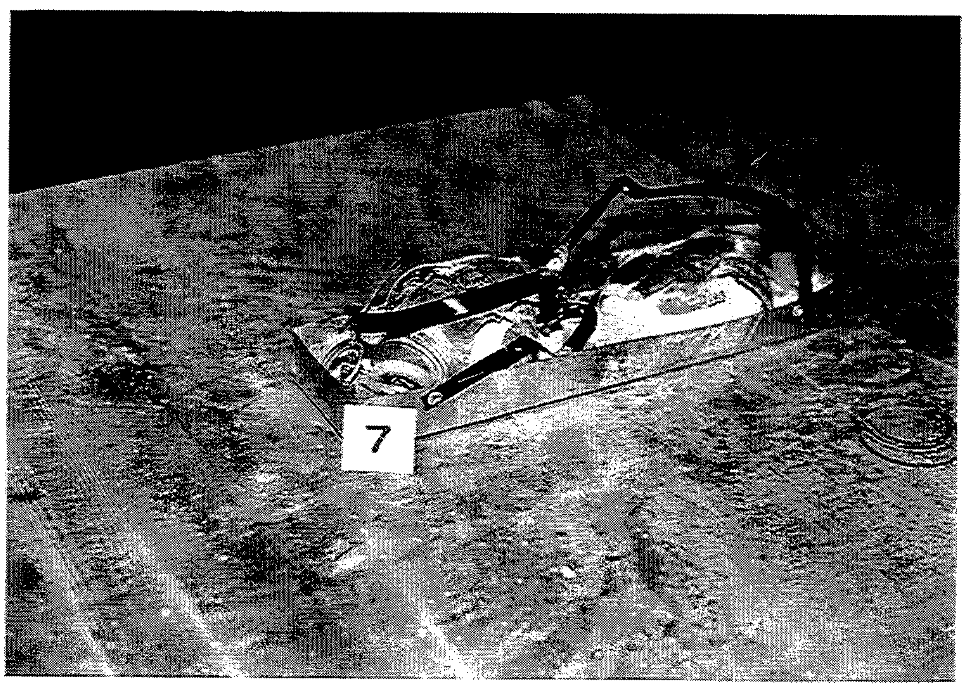


Figure 121
Debris from live M61 hand grenade test 7

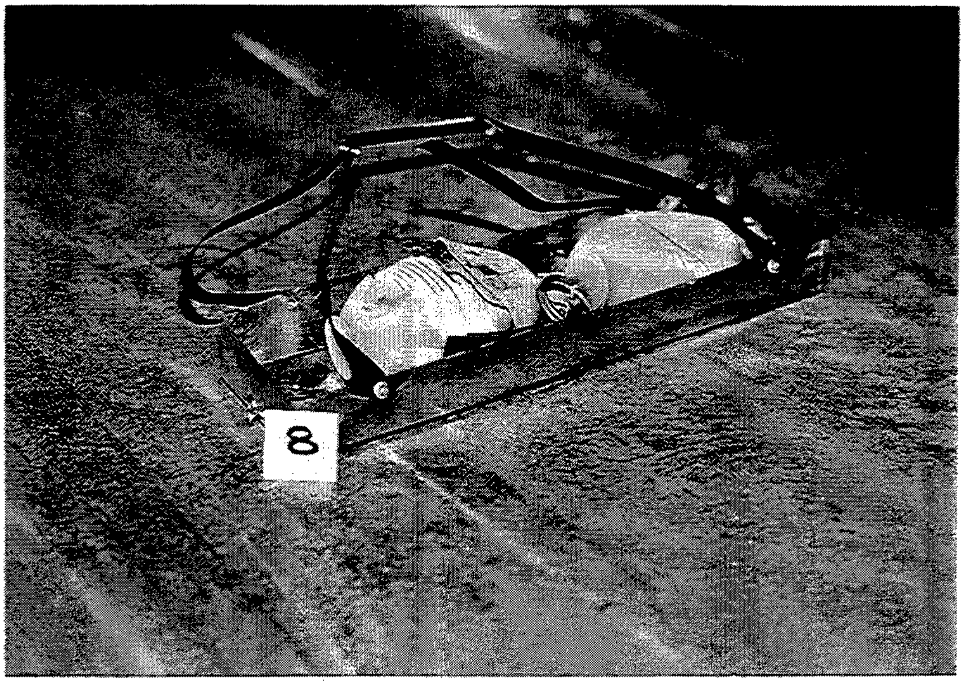


Figure 122
Debris from live M61 hand grenade test 8

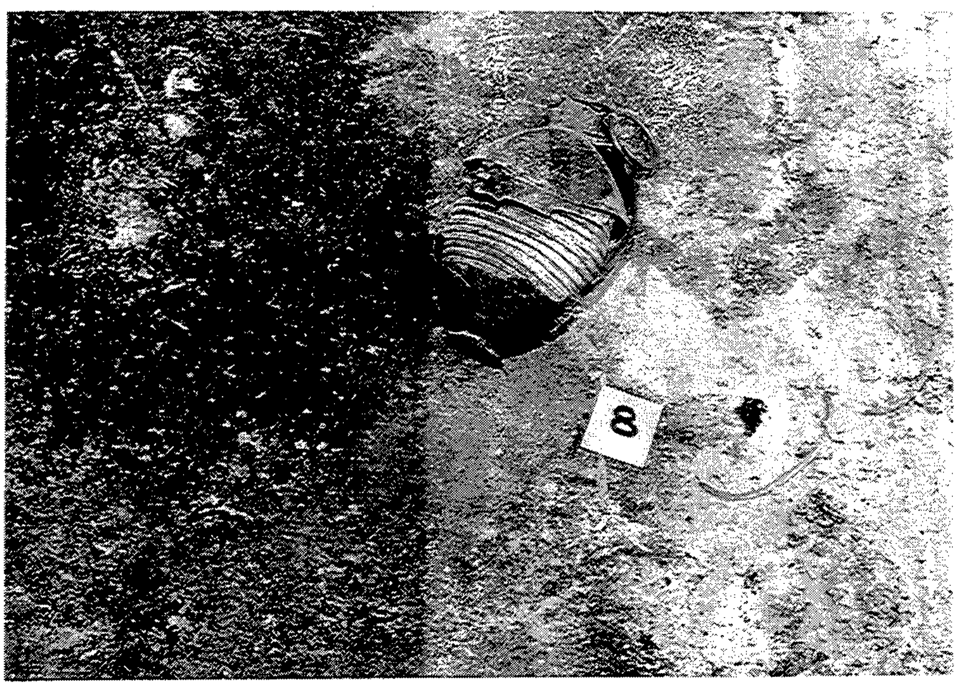


Figure 123
Debris from live M61 hand grenade test 8

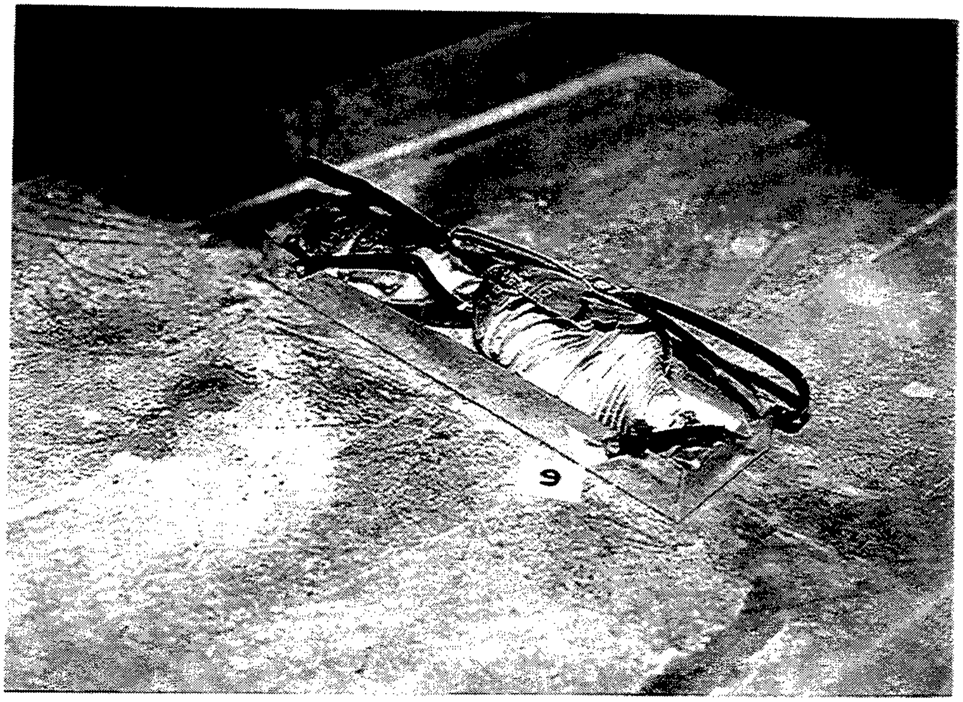


Figure 124
Debris from live M61 hand grenade test 9

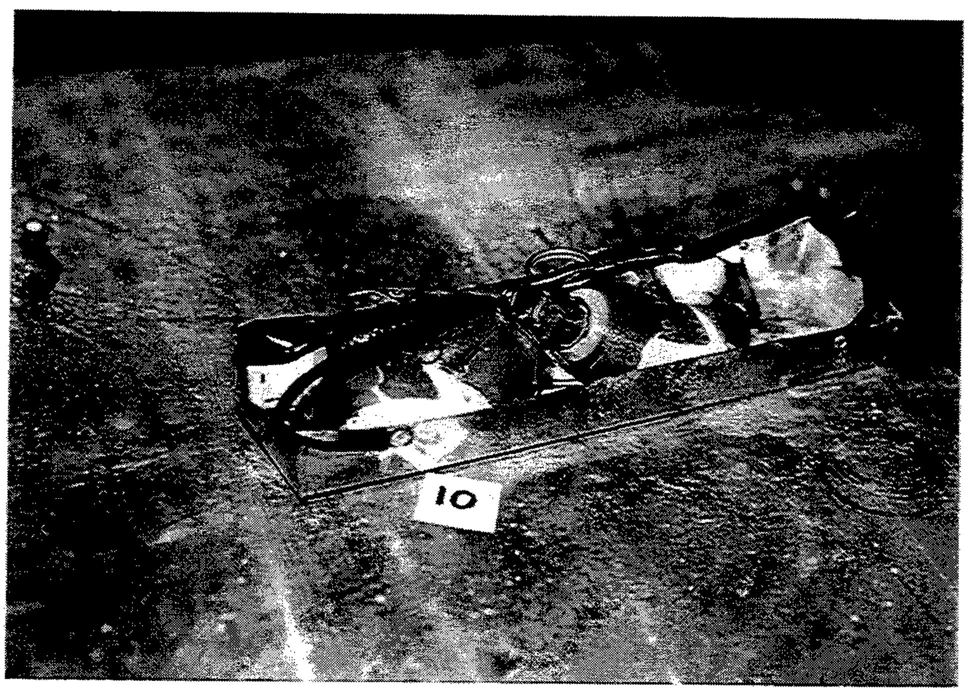


Figure 125
Debris from live M61 hand grenade test 10

Figure 126
Debris from live M61 hand grenade test 11

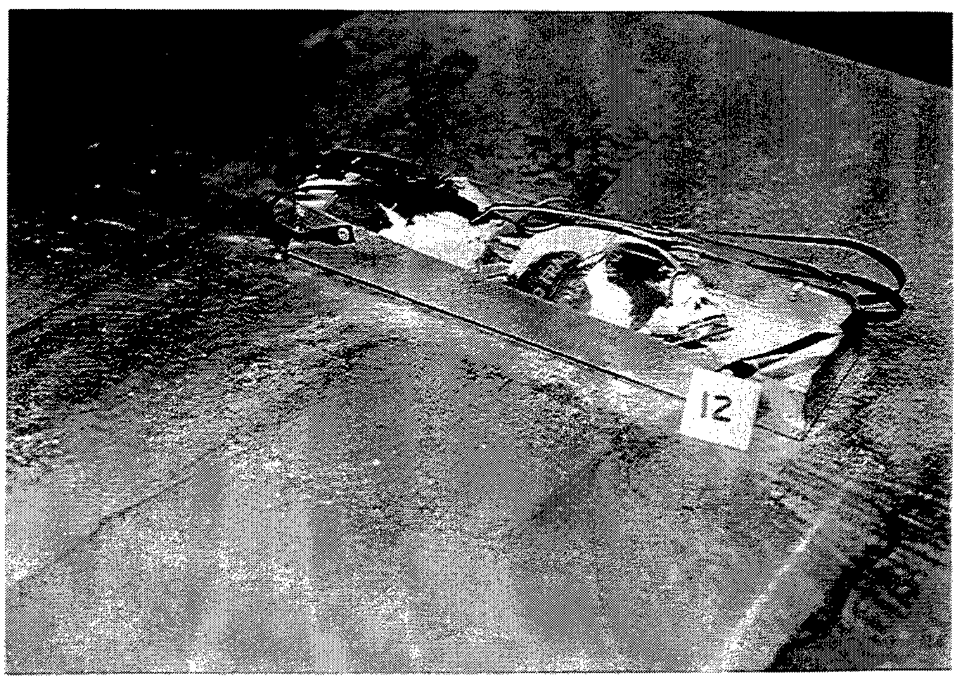


Figure 127
Debris from live M61 hand grenade test 12

Figure 128
Debris from live M61 hand grenade test 13

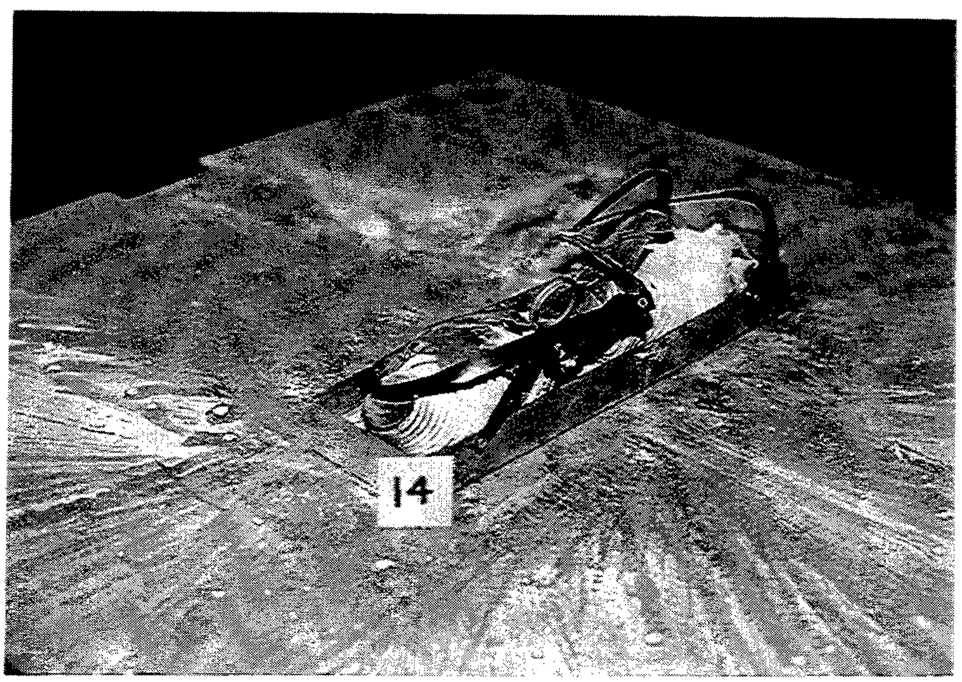


Figure 129
Debris from live M61 hand grenade test 14

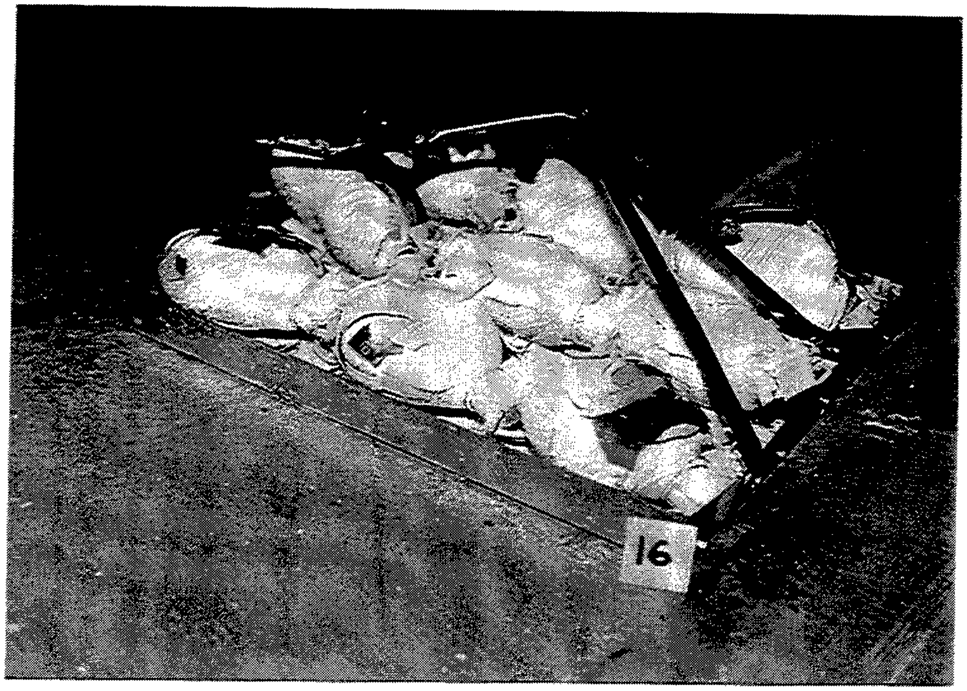


Figure 130
Debris from live M61 hand grenade test 16

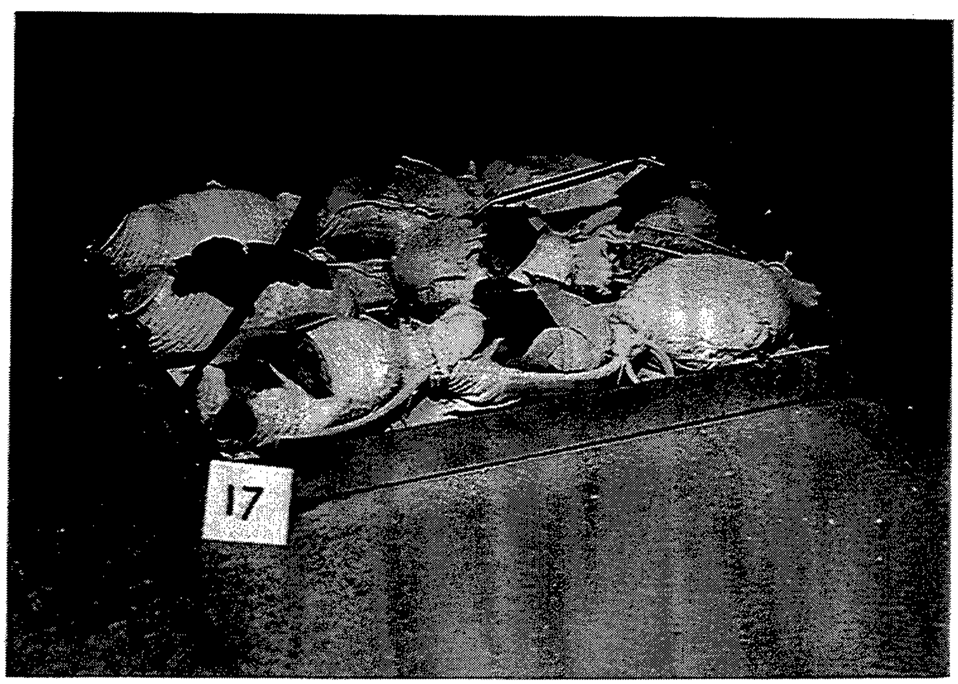


Figure 131
Debris from live M61 hand grenade test 17

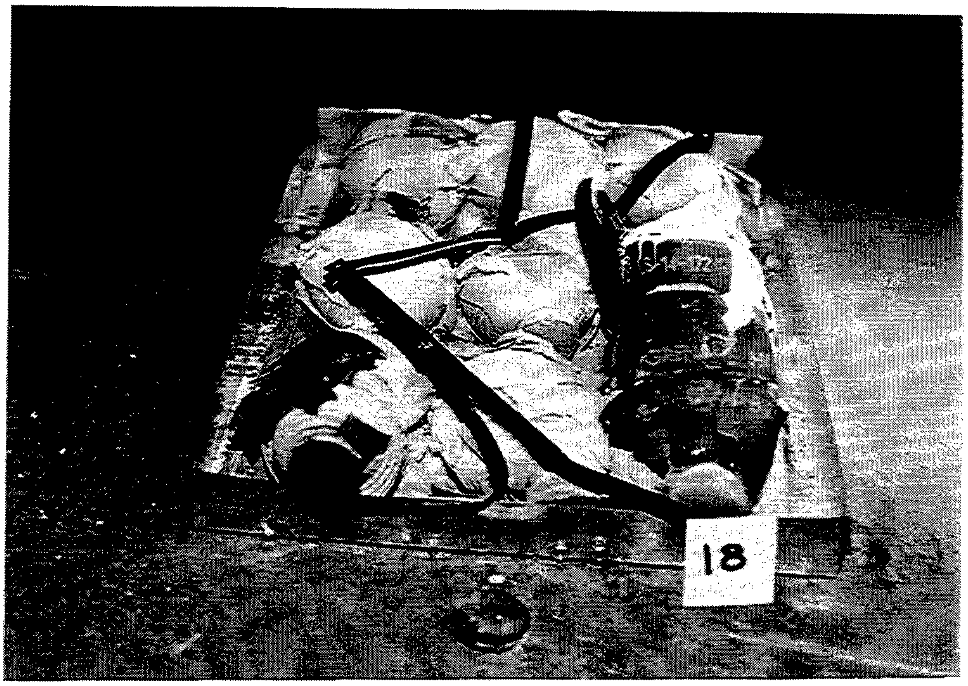


Figure 132
Debris from live M61 hand grenade test 18

Figure 133
Debris from live M61 hand grenade test 19

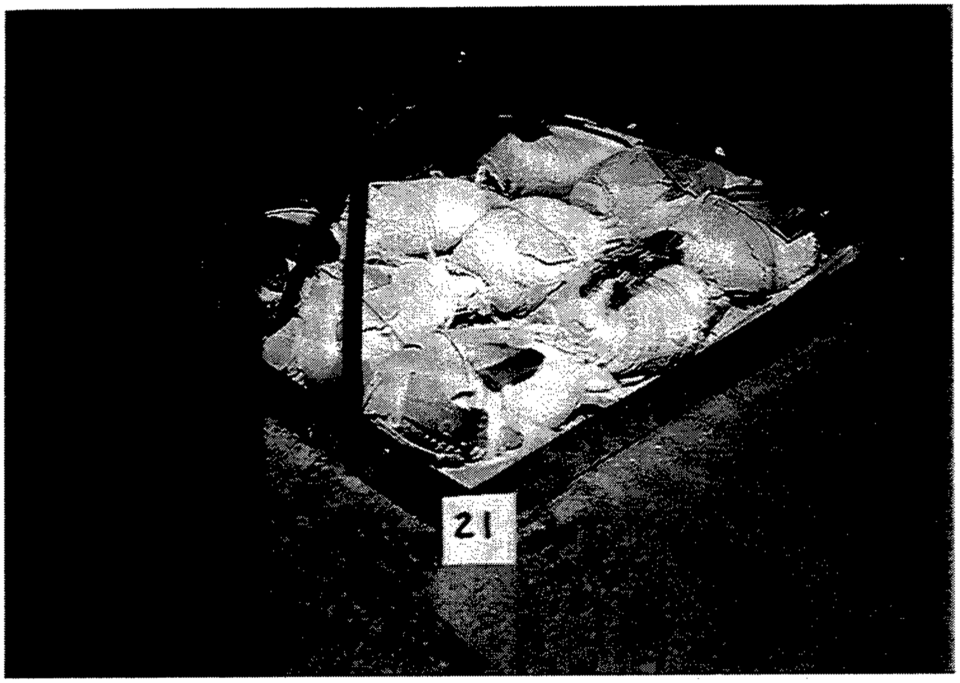


Figure 134
Debris from live M61 hand grenade test 21

Figure 135
Debris from live M61 hand grenade test 22

Figure 136
Debris from live M61 hand grenade test 37

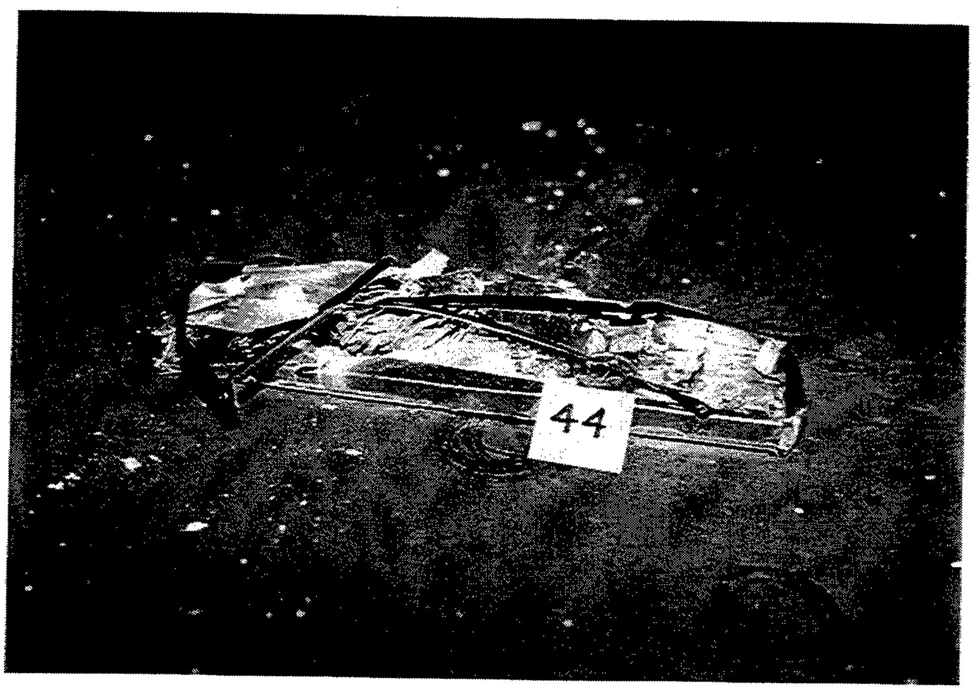


Figure 137
Debris from live M61 hand grenade test 44

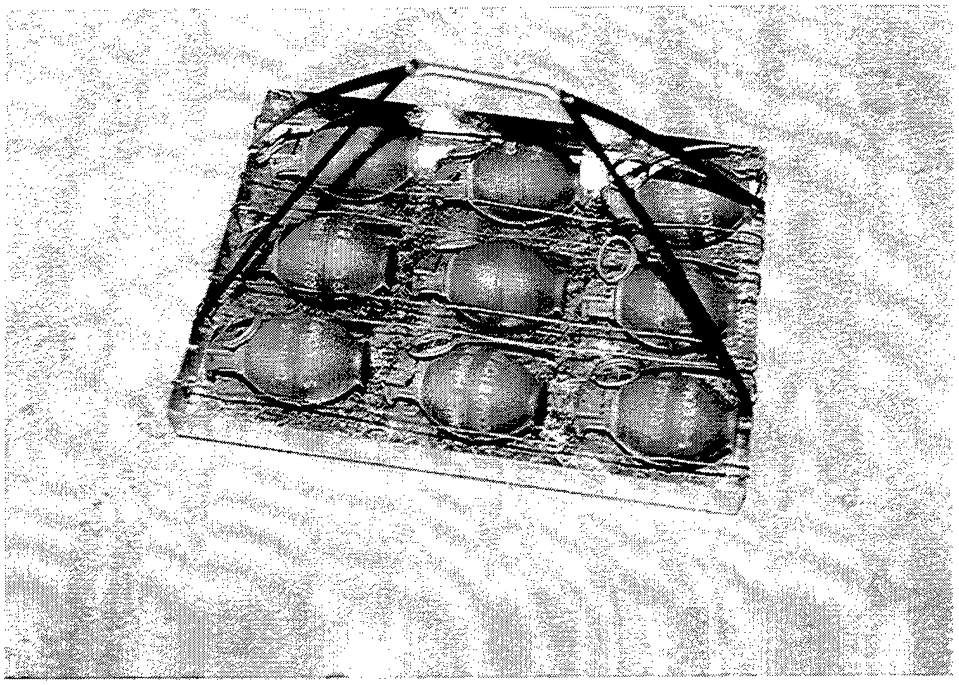


Figure 138
Modified munitions handling basket shoring for live M61 hand grenade test 59

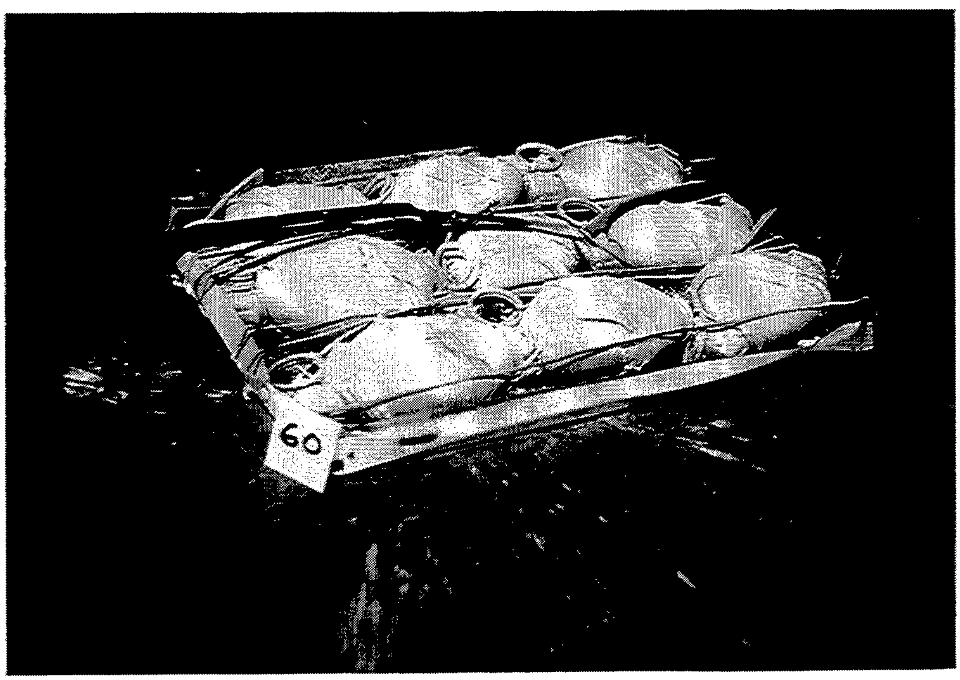


Figure 139
Debris from live M61 hand grenade test 60

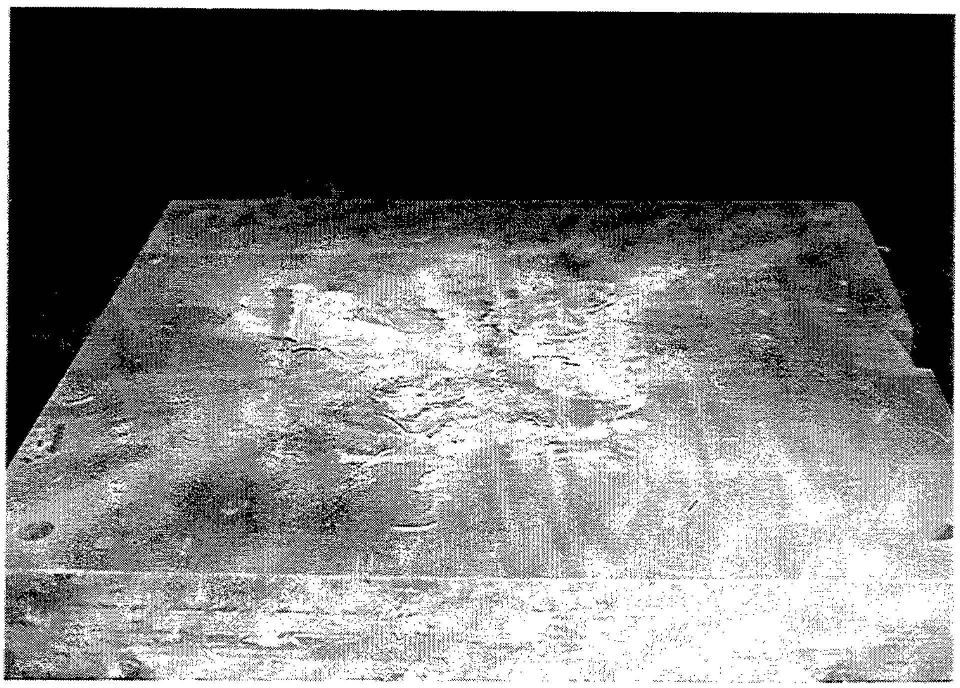


Figure 140
Lower press tooling after explosion

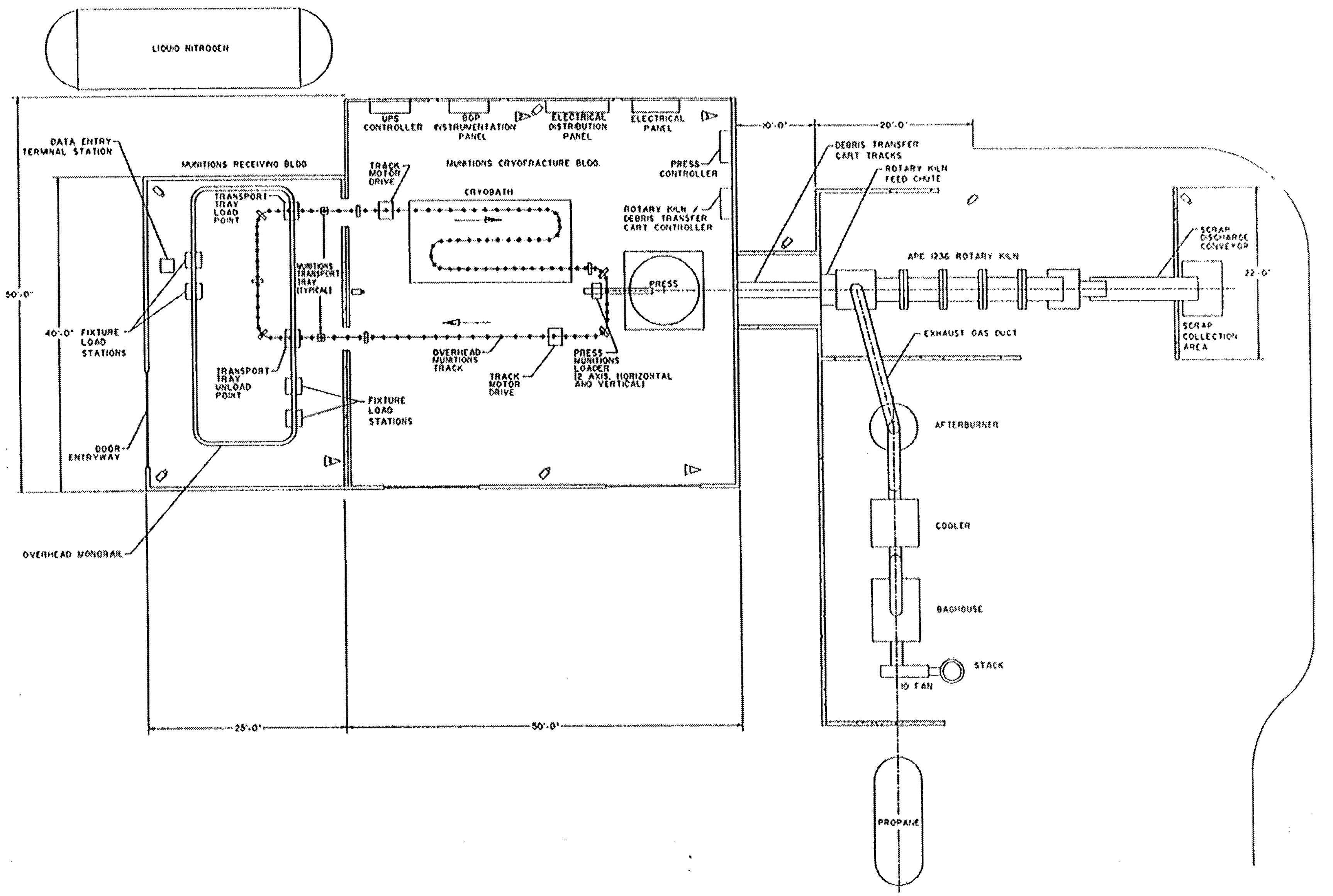


Figure 141
Munitions cryofracture facility - concept 1 plan

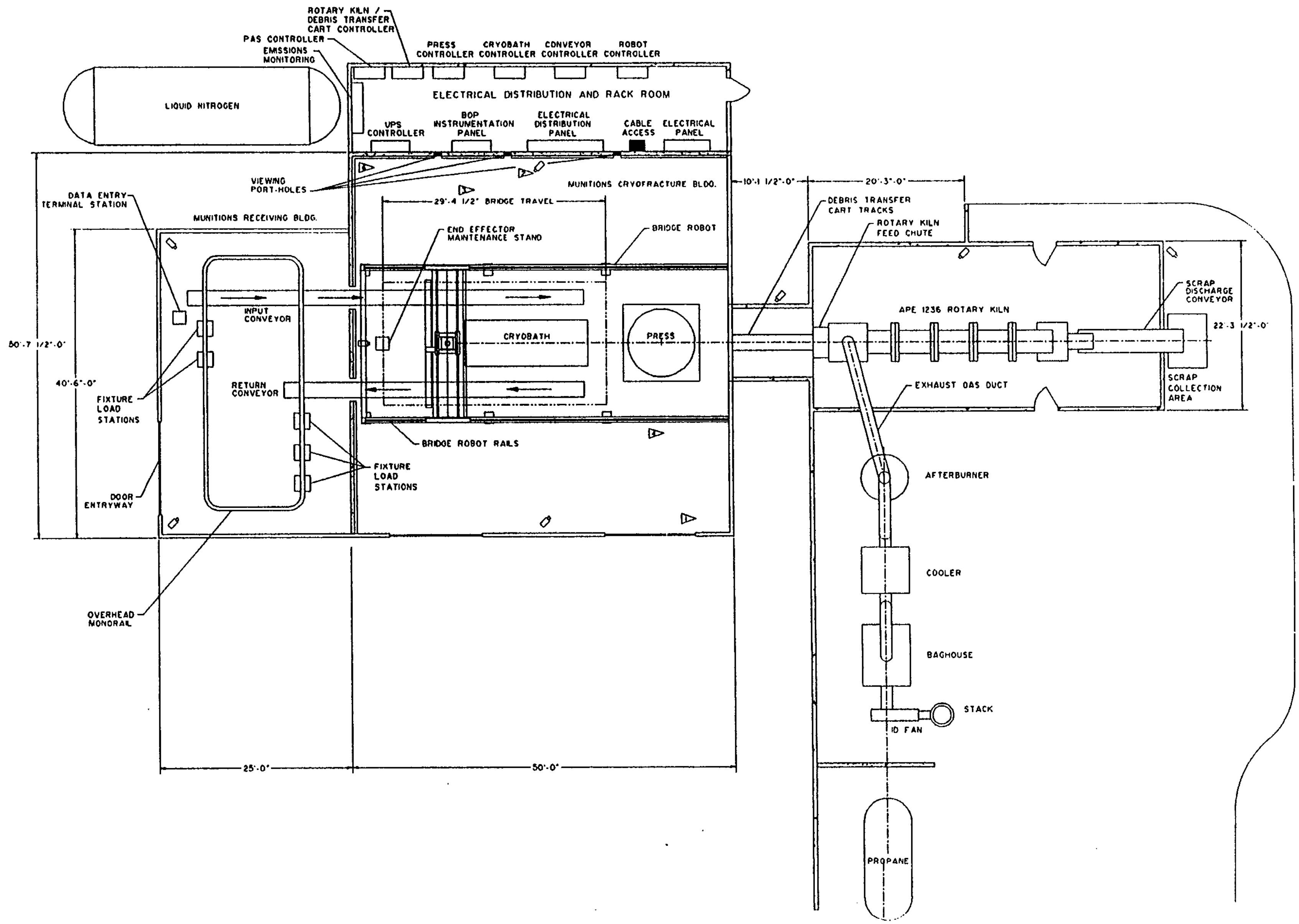
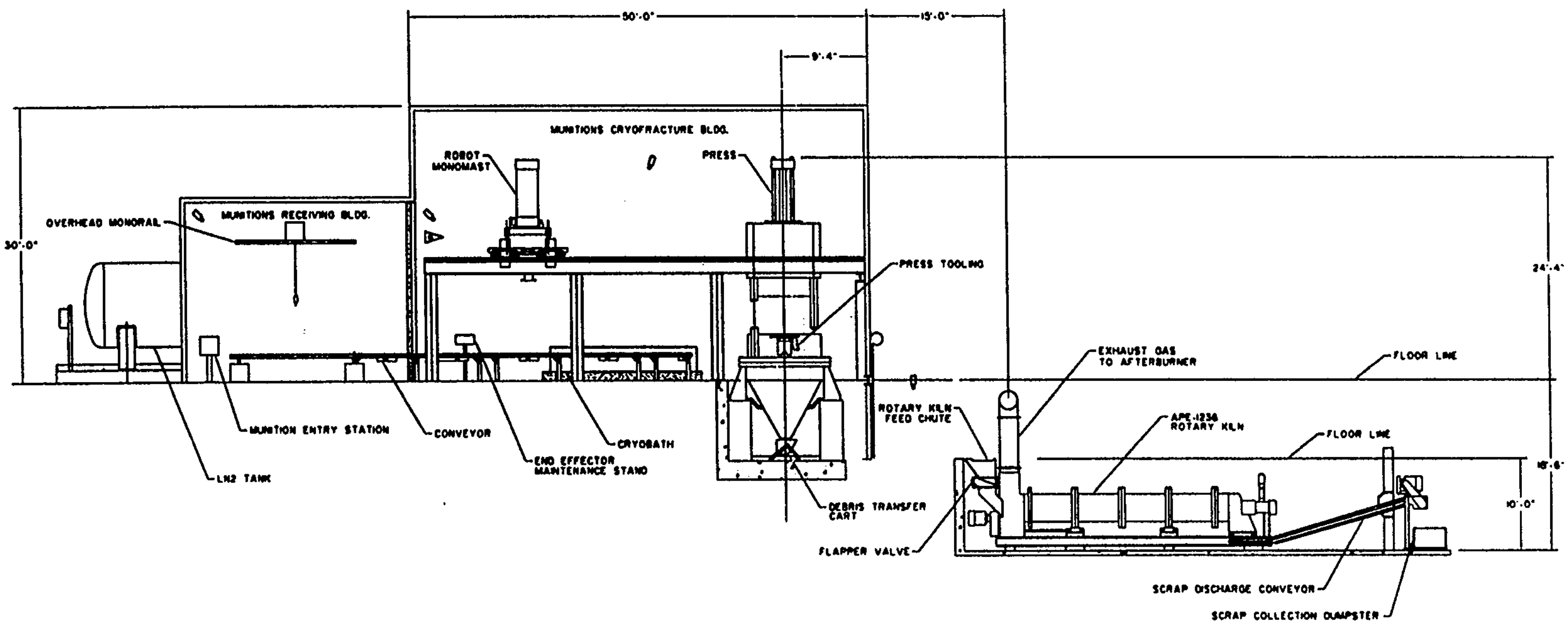


Figure 142
Munitions cryofracture facility - concept 2 plan



EQUIPMENT ARRANGEMENT ELEVATION

Figure 143
Munitions cryofracture facility - concept 2 elevation

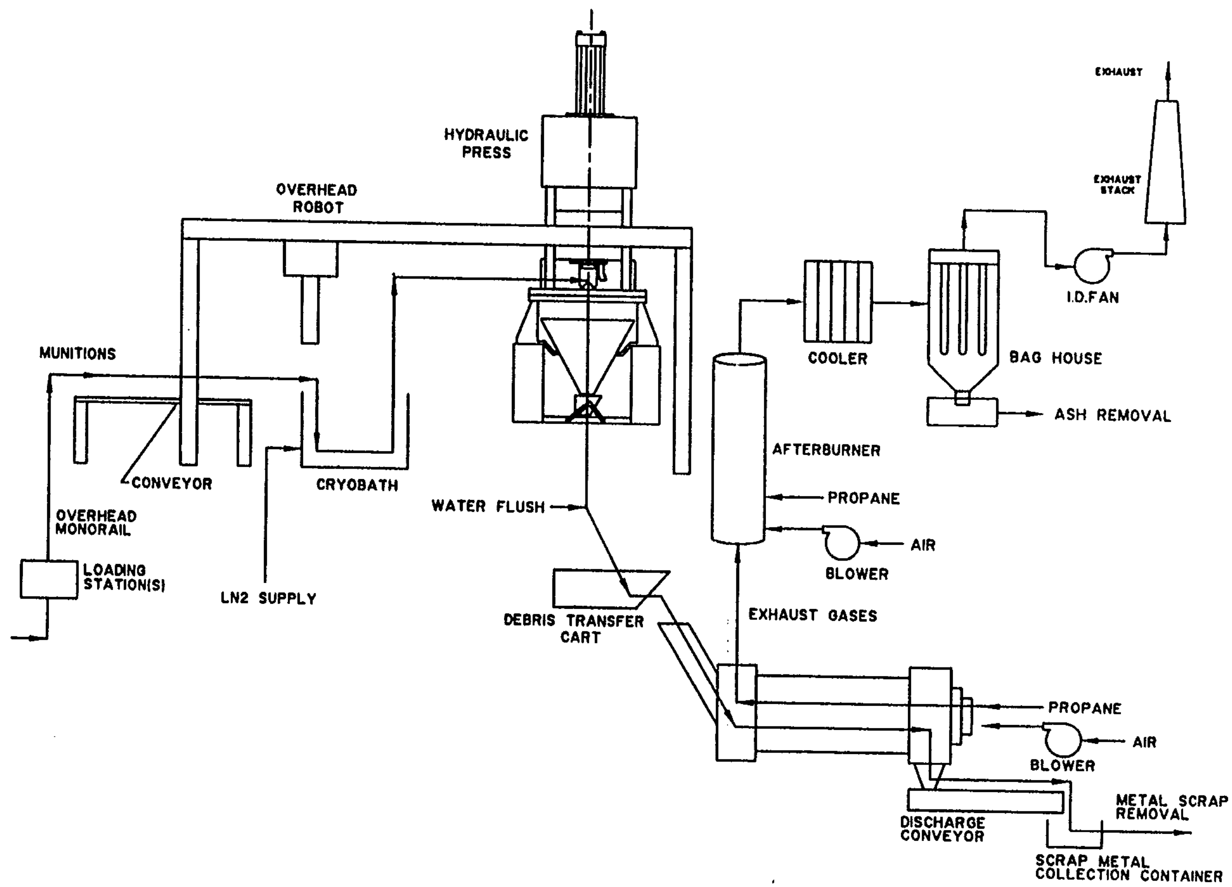


Figure 144
Munitions cryofracture facility - concept 2 process flow diagram

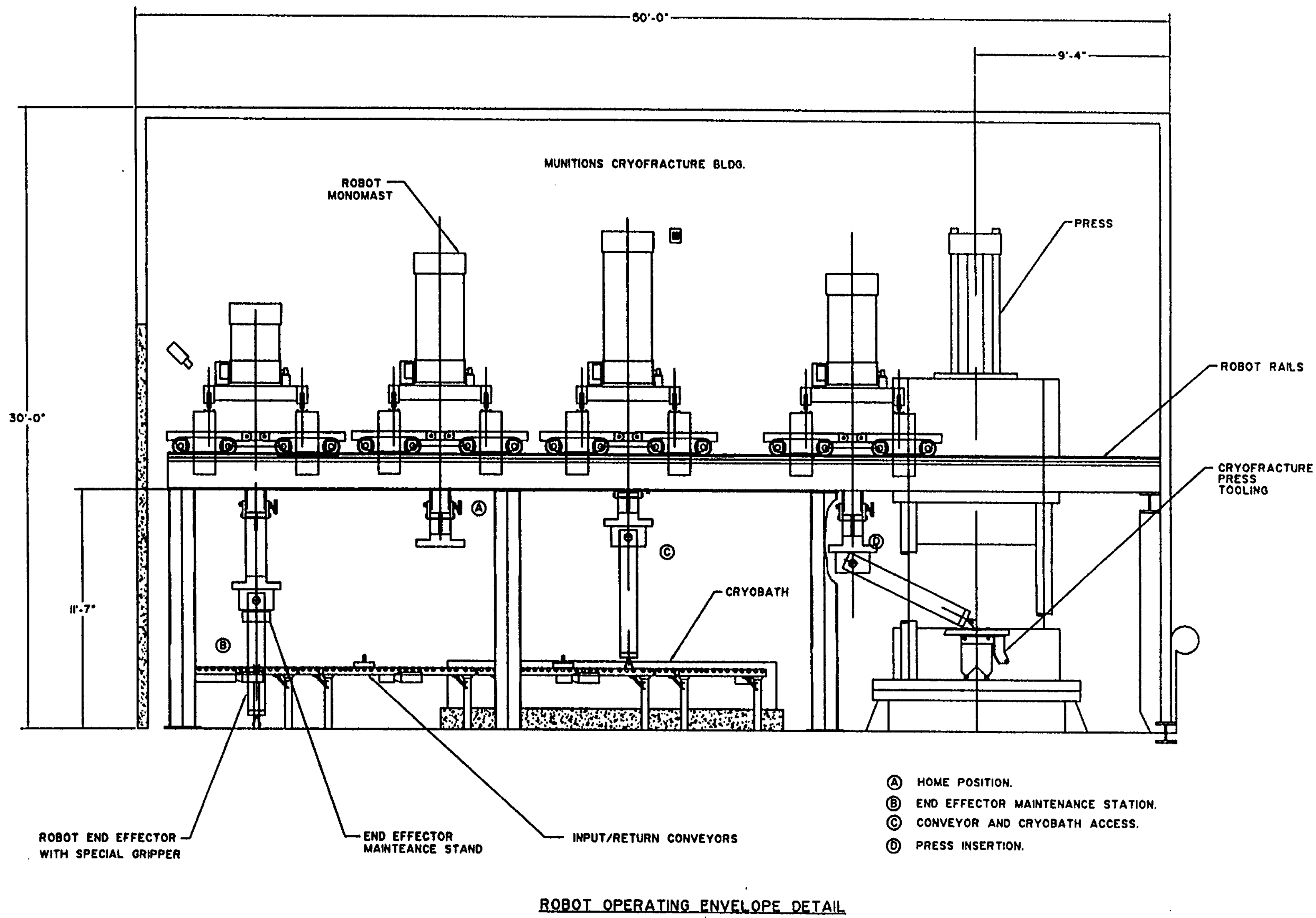


Figure 145
Munitions cryofracture facility - concept 2 gantry robot operating envelope

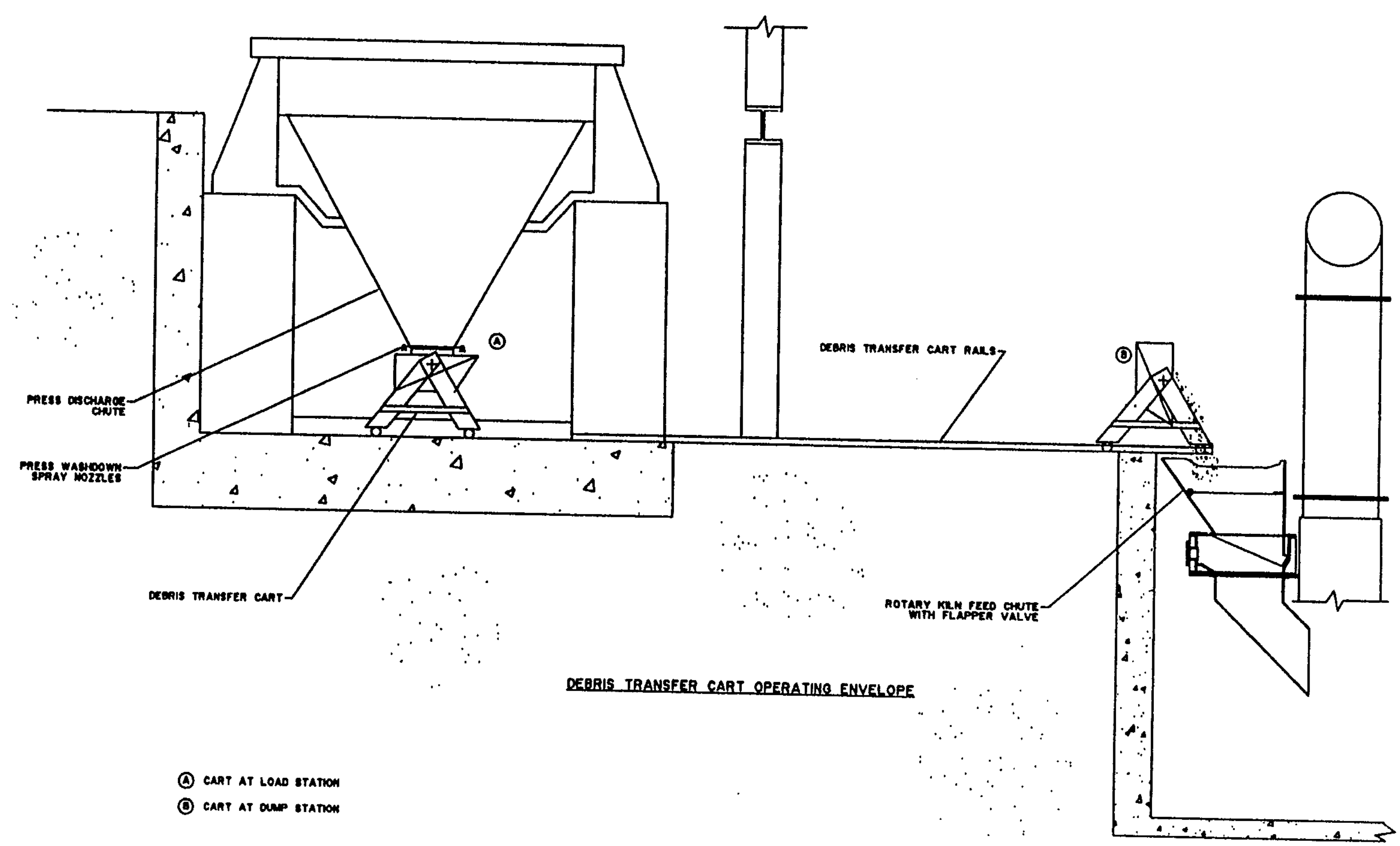


Figure 146
Munitions cryofracture facility - debris transfer cart operating envelope

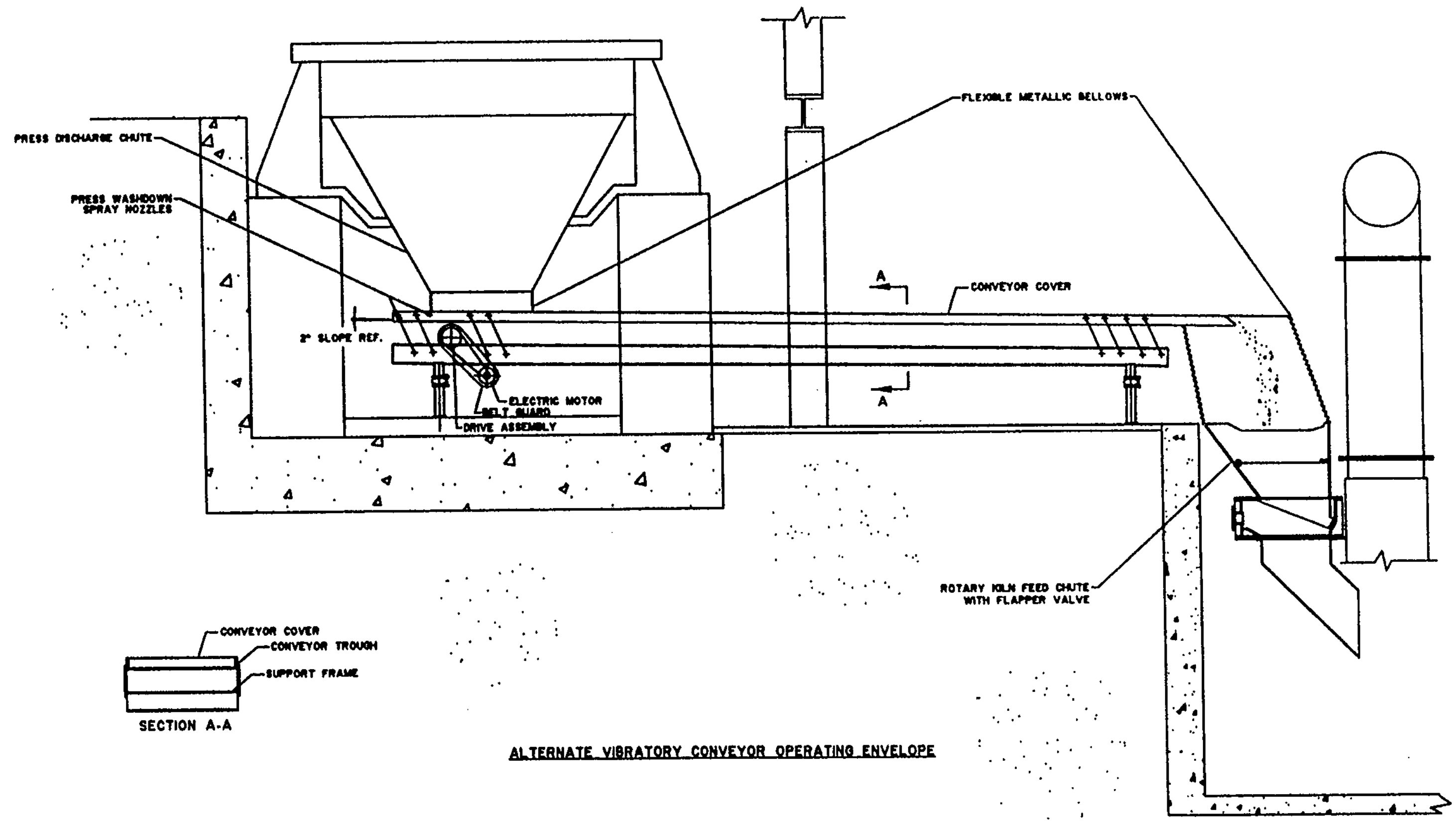


Figure 147
Munitions cryofracture facility - vibratory conveyor concept

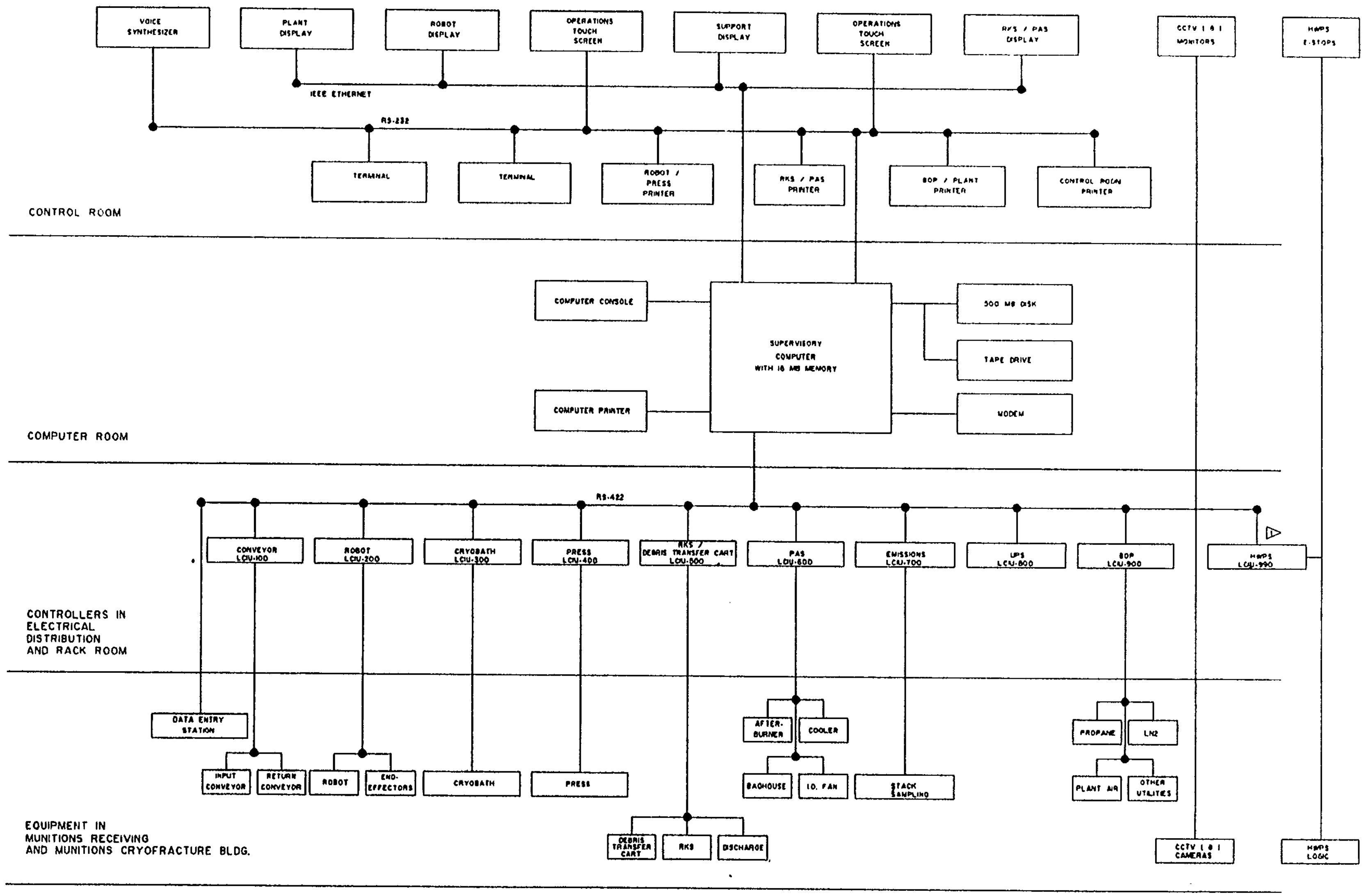


Figure 148
Munitions cryofracture facility - process control line diagram

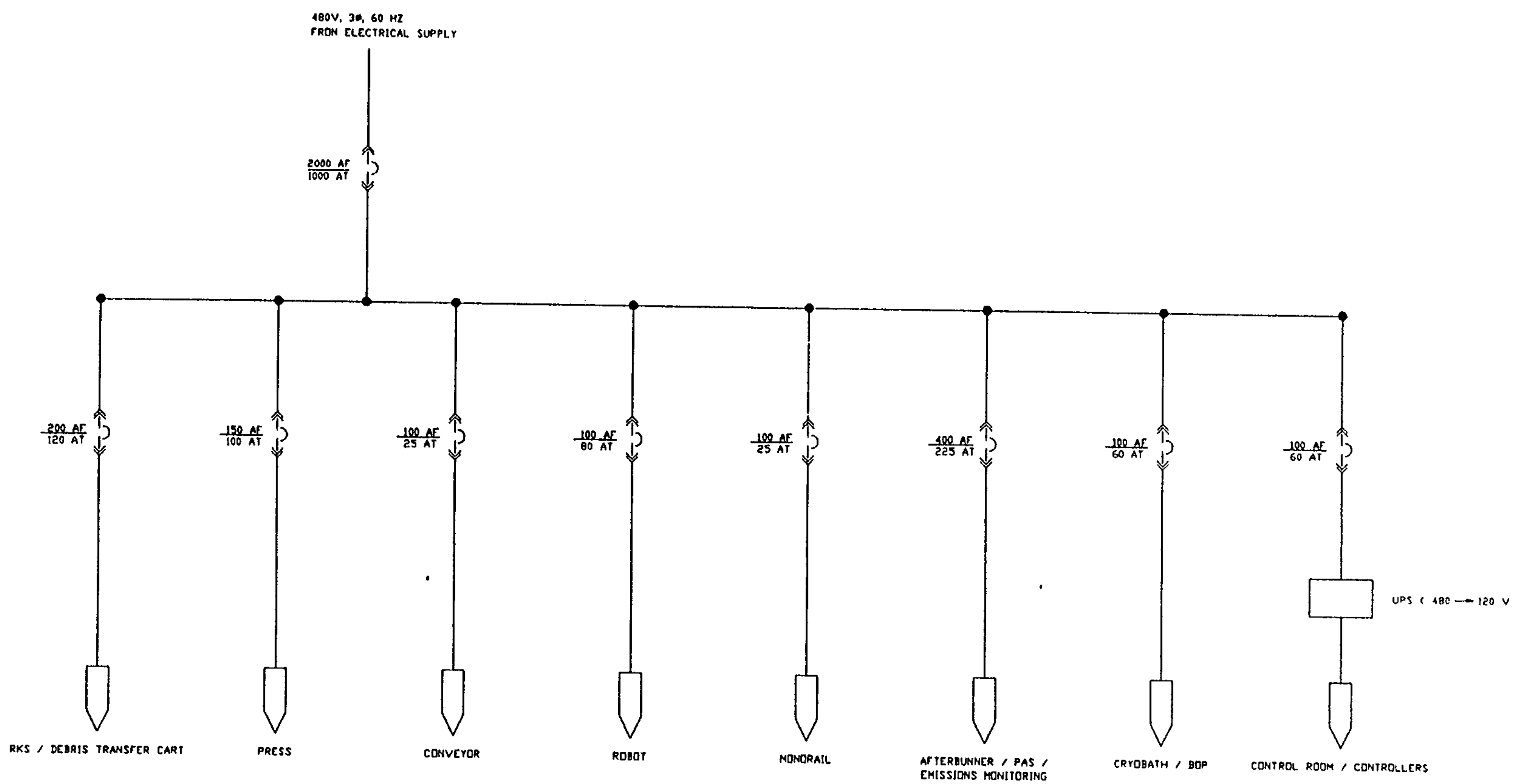


Figure 149
Munitions cryofracture facility - concept 2 single line diagram

NOTES:

1. All LCIU's ARE INTERFACED WITH THE SUPERVISORY COMPUTER.
2. ROTARY KILN AND POLLUTION ABATEMENT SYSTEM CONTROLS AND INSTRUMENTS ARE THOSE NORMALLY ASSOCIATED WITH THE APE-1236 ROTARY KILN AND ITS POLLUTION ABATEMENT SYSTEM.

MUNITIONS CRYOFRACTURE FACILITY
INTEGRATED PIPING AND INSTRUMENTATION DIAGRAM

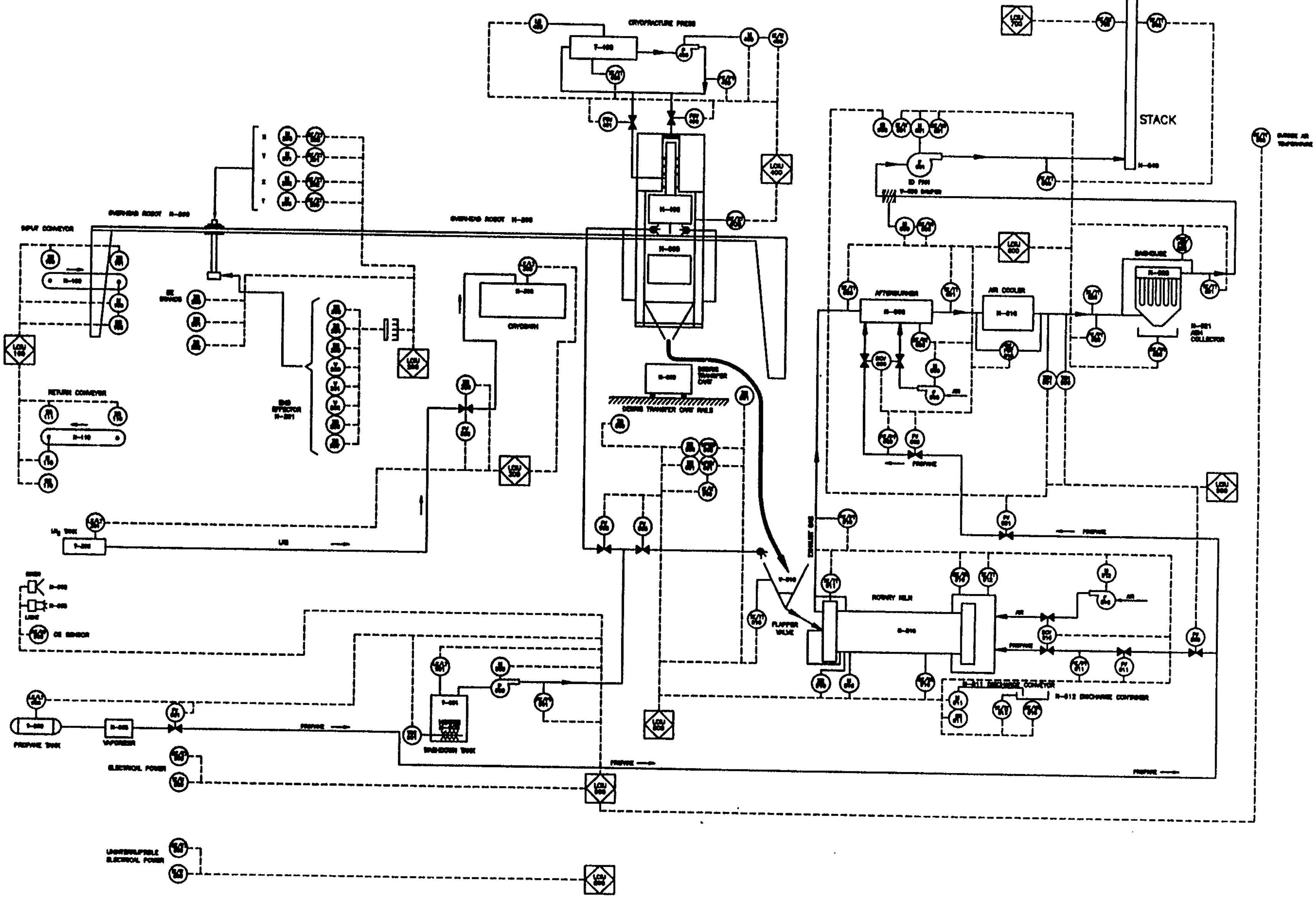


Figure 150
Munitions cryofracture facility - concept 2 piping and instrument diagram

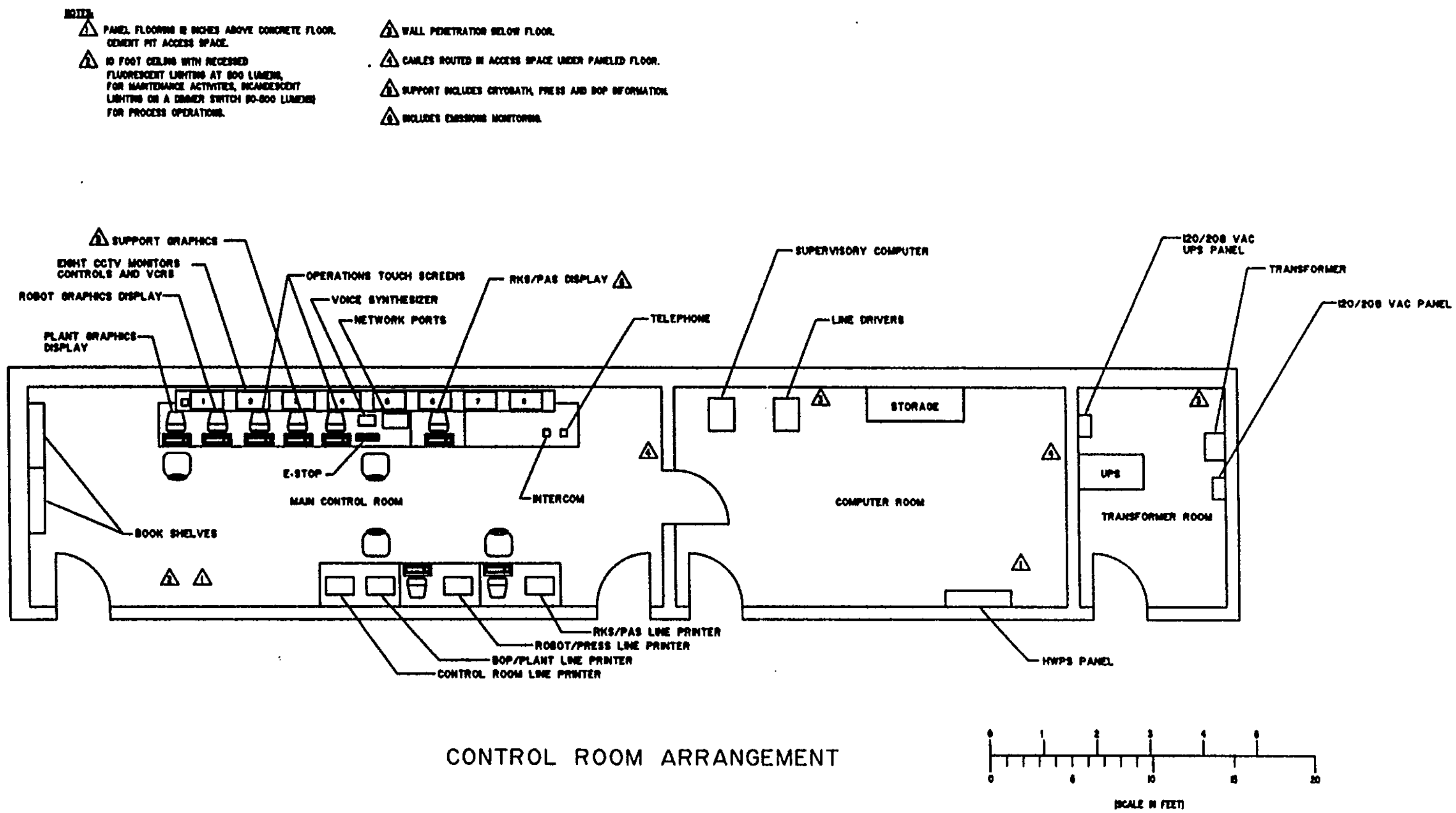
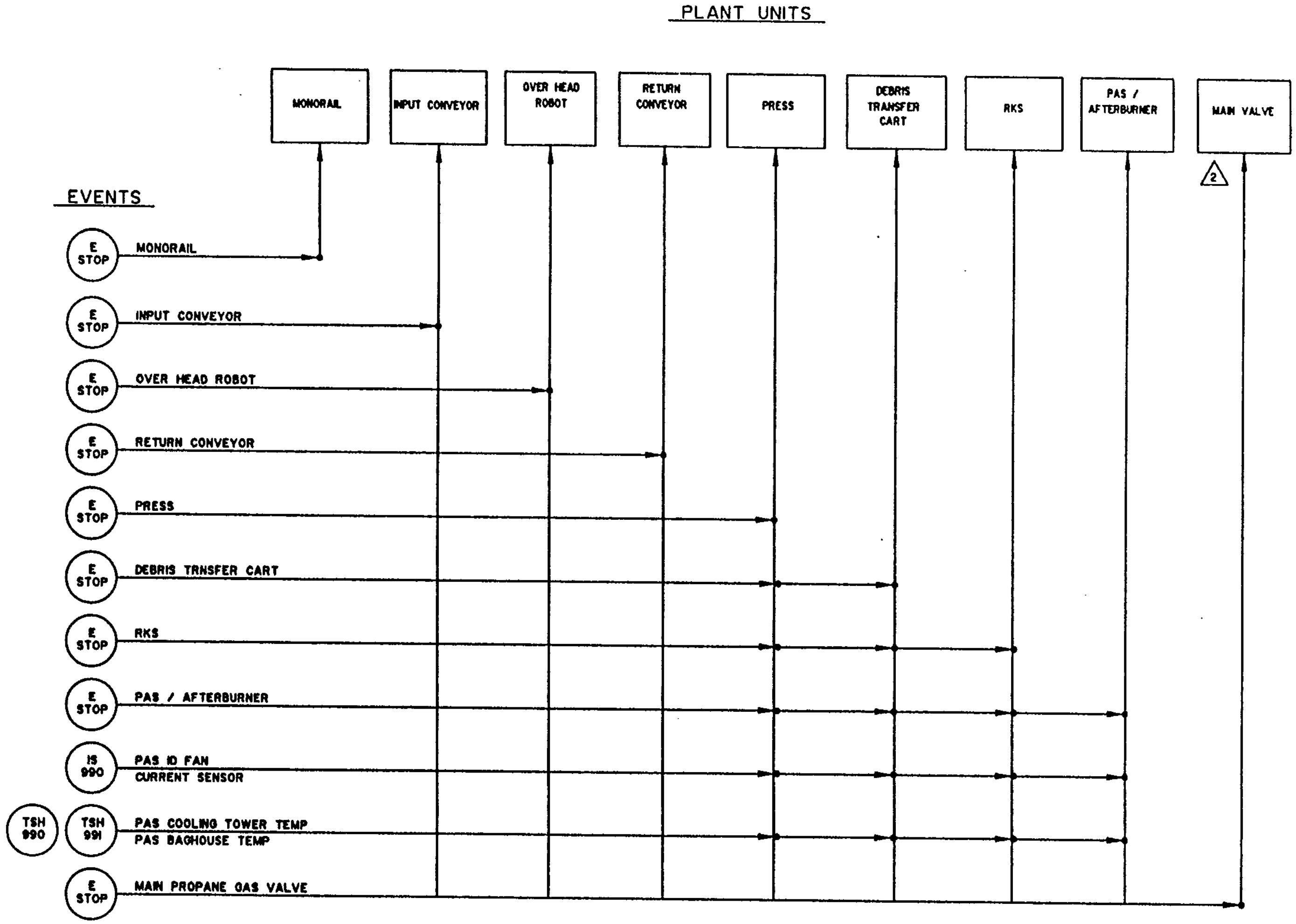


Figure 151
Munitions cryofracture facility - control room layout concept



NOTES:

1. THE HWPS IS A SEPARATE STAND ALONE SYSTEM THAT UTILIZES SEPARATE DIVERSE INSTRUMENTATION AND CONTROL COMPONENTS.

2. THE PROPANE GAS VALVES ARE HARDWIRED TO OPERATE WITH THE HWPS E-STOP BUTTONS.
FV-901 AFTERBURNER
FV-900 RKS

Figure 152
Munitions cryofracture facility - hardwired protection system logic diagram

cryobath = 600 inches = 50 ft of conveyor length above cryobath.
Cryofracture Time = 1 munition/second.

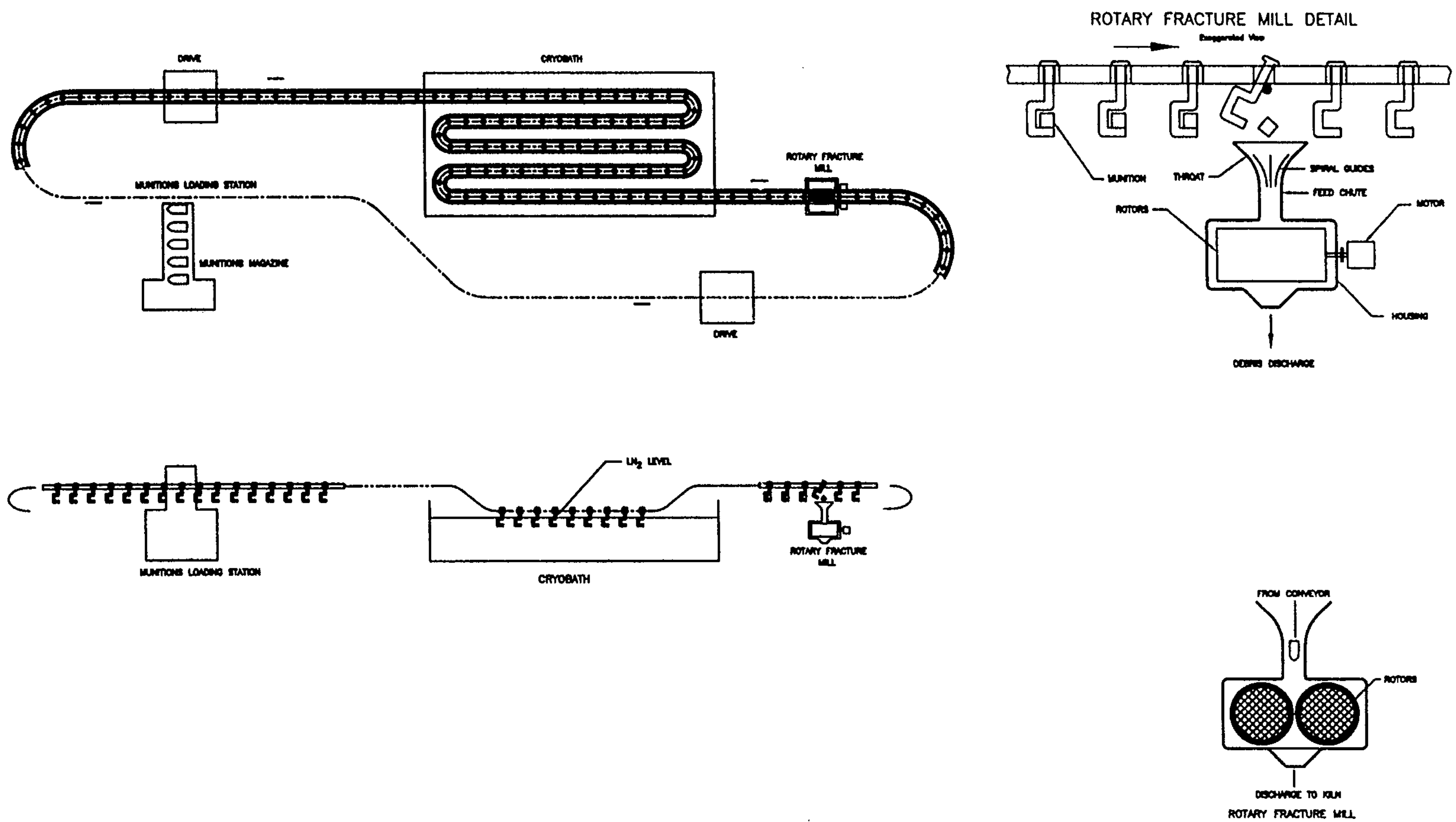


Figure 153
Munitions cryofracture facility - rotary fracture mill concept

Table 1
Munitions previously cryofractured

Munition type	Packaging	No. of munitions cryofractured
155-mm projectile	Bare, burstered	1204
105-mm cartridge	2 in wood box, fuzed & burstered	70
105-mm projectile	Bare, fuzed & burstered, fractured 2 at-a time	1624
4.2-in. mortar	2 in wood box, fuzed & burstered	98
4.2-in. mortar	Bare, fuzed, fractured 2 at-a-time	400
Land mine	3 in metal drum with fuzes, initiators, & bursters	99
115-mm rocket	1 in firing tube, fuzed & burstered	200

Table 2
Throughput rate limits for a production demilitarization facility

Cryofracture process component	Limiting factors	Maximum allowable Throughput rate, munitions/hr	
		Munition type	
		M42/M46/ M77	M67
Existing DPG press	Tonnage (400 tons) cycle time - 1 min.	3600	2940
DPG press with new main motor	Tonnage (750 tons) cycle time - 1 min.	6840	5520
APE-1236 rotary Kiln	Explosive limit @ 1 rpm	4440	720

Table 3
Munitions cryofractured

Munition type	Inert grenades	Live grenades
M42/M46/M77 grenade	267 M42/M46 only	433 M77 only
M61 hand grenade	none	321
M67/M69 hand grenade	103 M69 only	330 M67 only

Table 4
Munitions characteristics

Munition Type	M42/M46/M77 Grenade	M61 Hand Grenade	M67 Hand Grenade	M69 Hand Grenade
Weight	200 gm/209 gm/200gm	454 gm	397 gm	397 gm
Main Explosive	30.5 gm Comp A-5	164 gm Comp B	184 gm Comp B	None
Fuze Type	M223 General purpose w/M55 detonator	M204A1 or M204A2 Pyrotechnic delay detonating w/M42 primer	M213	M228
Fuze Explosives	Upper charge - 15 mg NOL#130 Intermediate charge - 51 mg lead azide Lower charge - 19 mg RDX	M42 Primer - 0.31 to 0.36 gr PA-101 Delay - 20 gr Delay Comp Type II Ignition charge - 1 gr lead styphnate Intermediate charge - 4 gr lead azide Igniter - 12 gr black powder	M42 Primer - 0.31 to 0.36 gr PA-101 Delay - 20 gr Delay Comp Type II Ignition charge - 1 gr lead styphnate Intermediate charge - 4 gr lead azide Igniter - 12 gr black powder	M42 Primer - 0.31 to 0.36 gr PA-101 Delay - 20 gr Delay Comp Type II Igniter - black powder

Table 5
Test results summary - inert M42/M46 grenades

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade spacing (side x end)	Purpose of Test
8/1/95	1	3	I	20	1.375	Yes	na x 1/2	Establish press spacing
8/1/95	2	3	I	20	1.25	Yes	na x 1/2	Establish press spacing
8/1/95	3	3	I	20	1.125	Yes	na x 1/2	Establish press spacing
8/1/95	4	3	I	20	1.0	Yes	na x 1/2	Establish press spacing
8/1/95	5	3	I	20	1.25	Yes	na x 1/2	Repetition at selected press spacing
8/1/95	6	3	I	20	1.25	Yes	na x 1/2	Repetition at selected press spacing
8/1/95	7	3	I	20	1.25	No	na x 1/2	No LN_2 in basket
8/2/95	8	3	I	20	1.25	No	na x 1/2	No LN_2 in basket
8/2/95	9	3	I	20	1.25	No	na x 1/2	No LN_2 in basket
8/2/95	10	3	I	10	1.25	No	na x 1/2	Establish cooldown time
8/2/95	11	3	I	8	1.25	No	na x 1/2	Establish cooldown time
8/2/95	12	3	I	6	1.25	No	na x 1/2	Establish cooldown time
8/2/95	13	3	I	10	1.25	No	na x 1/2	Repetition at selected cooldown time
8/2/95	14	3	I	10	1.25	No	na x 1/2	Repetition at selected cooldown time
8/2/95	15	3	I	10	1.375	No	na x 1/2	80 sec. warmup before fracture
8/2/95	16	3	I	10	1.375	No	na x 1/2	100 sec. warmup before fracture
8/2/93	17	3	I	10	1.375	No	na x 1/2	120 sec. warmup before fracture
8/2/95	18	9	II	10	1.375	No	1 x 1/2	Establish minimum grenade spacing
8/2/95	19	9	II	10	1.375	No	3/4 x 1/2	Establish minimum grenade spacing
8/2/95	20	9	II	10	1.375	No	1/2 x 1/2	Establish minimum grenade spacing
8/3/95	21	9	II	10	1.375	No	1/4 x 1/2	Establish minimum grenade spacing
8/3/95	22	9	II	10	1.375	No	zero x 1/2	Establish minimum grenade spacing
8/3/95	23	9	II	10	1.375	No	zero x -7/8	Establish minimum grenade spacing
8/3/95	24	9	II	10	1.375	No	zero x full nest	Establish minimum grenade spacing

Table 5
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, In	LN_2 in Basket?	Grenade spacing (side x end)	Purpose of Test
8/3/95	25	9	II	10	1.375	No	zero x 1/2	Repetition at selected grenade spacing
8/3/95	26	9	II	10	1.375	No	zero x 1/2	Repetition at selected grenade spacing
8/8/95	27	45	III	10	1.375	No	zero x 1/2	Large quantity cryofracture
8/9/95	28	45	III	10	1.375	No	zero x 1/2	Large quantity cryofracture
8/9/95	29	45	III	10	1.375	No	zero x 1/2	Large quantity cryofracture
8/9/95	30	9	II	10	full crush	No	zero x 1/2	Investigate full crush effects

Table 6
Test results summary - live M77 grenades

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown Time, min.	Press Closure Spacing, in.	Fracture Load, tons	Comments
8/22/95	1	1	I	10	1.312	na	
8/22/95	2	1	I	10	1.312	na	
8/22/95	3	1	I	10	1.312	na	
8/23/95	4	2	I	10	1.312	na	
8/23/95	5	3	I	10	1.312	na	
8/23/95	6	9	II	10	1.312	na	Less than desired explosive accessing
8/24/95	7	9	II	10	1.25	na	Press closure spacing reduced
8/24/95	8	45	III	10	1.25	303	Less than desired grenade accessing. One grenade exploded in furnace. Damage limited to furnace grate.
8/29/95	9	45	III	10	1.25	233	Side-to-side grenade spacing increased from zero to 0.25 in.
8/29/95	16	1	I	10	0.25	96	Full crush test. Explosion during crush.
8/30/95	17	1	I	10	0.5	75	Minimum press closure spacing - 0.5 in. Explosion during crush.
8/30/95	18	1	I	10	0.75	69	Minimum press closure spacing - 0.75 in.
8/30/95	19	1	I	10	0.75	66	Same as Test 18
8/30/95	20	1	I	10	0.75	68	Same as Test 18
8/30/95	21	1	I	10	0.75	74	Same as Test 18
8/30/95	22	1	I	10	0.75	72	Same as Test 18
8/30/95	23	1	I	10	0.75	70	Same as Test 18
8/31/95	24	1	I	10	0.75	70	Same as Test 18
8/31/95	25	1	I	10	0.75	72	Same as Test 18
8/31/95	10	44	III	10	1.18	289	Side-to-side grenade spacing - 0.25 in. Press closure spacing reduced from 1.25 to 1.18 in.

Table 6
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown Time, min.	Press Closure Spacing, in.	Fracture Load, tons	Comments
8/31/95	11	44	III	10	1.18	276	Same as Test 10
9/12/95	12	44	III	10	1.18	334	Same as Test 10
9/12/95	13	44	III	10	1.18	272	Same as Test 10
9/12/95	14	44	III	10	1.18	321	Same as Test 10
9/12/95	15	44	III	10	1.18	331	Same as Test 10. Brush fire started by debris from open grate furnace burned a wide area around the test facility. Damage limited to wiring between control center and main bldg.
9/26/95	26	43	III	10	1.18	254	This test cryofractured all remaining live M77 grenades

Tests 4-15 and 26 used 0.5 in. end-to-end grenade spacing
Tests 6-8 used zero side-to-side grenade spacing. Tests 9-15 and 26 used 0.25 in. side-to-side grenade spacing.
Tests 10-15 and 26 used an inert M42 in the center of the grenade array to avoid the tooling depression in that area caused during Test 16.

Table 7
Test results summary - inert M69 hand grenades

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade spacing (side x end)	Purpose of Test
8/9/95	1	2	I	20	2.25	Yes	na x 1	Establish press spacing
8/9/95	2	2	I	20	2.125	Yes	na x 1	Establish press spacing
8/9/95	3	2	I	22	2.0	Yes	na x 1/2	Establish press spacing
8/9/95	4	2	I	20	2.0	Yes	na x 1/2	Repetition at selected press spacing
8/9/95	5	2	I	20	2.0	Yes	na x 1/2	Repetition at selected press spacing
8/9/95	6	2	I	10	2.0	No	na x 1/2	No LN_2 in basket
8/9/95	7	2	I	10	2.0	No	na x 1/2	No LN_2 in basket
8/9/95	8	2	I	10	2.0	No	na x 1/2	No LN_2 in basket
8/9/95	9	2	I	8	2.0	No	na x 1/2	Establish cooldown time
8/9/95	10	2	I	6	2.0	No	na x 1/2	Establish cooldown time
8/9/95	11	2	I	10	2.0	No	na x 1/2	Repetition at selected cooldown time
8/10/95	12	2	I	10	2.0	No	na x 1/2	80 sec. warmup before fracture
8/10/95	13	2	I	10	2.0	No	na x 1/2	100 sec. warmup before fracture
8/10/95	14	2	I	10	2.0	No	na x 1/2	120 sec. warmup before fracture
8/10/95	15	9	II	10	2.0	No	zero x zero	Establish minimum grenade spacing
8/10/95	16	9	II	10	2.0	No	zero x zero	Repetition at selected conditions
8/10/95	17	9	II	10	2.0	No	zero x zero	Repetition at selected conditions
8/10/95	18	16	II	13	2.0	No	zero x zero	Large quantity cryofracture
8/10/95	19	16	II	10	2.0	No	zero x zero	Large quantity cryofracture
8/10/95	20	16	II	10	2.0	No	zero x zero	Large quantity cryofracture

Table 8
Test results summary - live M67 hand grenades

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown Time, min.	Fracture Load, tons	Comments
9/26/95	1	1	I		na	Good fracture and burn.
9/26/95	2	1	I		na	Good fracture and burn.
9/27/95	3	1	I		na	Press malfunctioned, but cryofracture was successfully completed. Good burn.
9/27/95	4	2	I		na	Good fracture and burn.
9/27/95	5	3	II		na	Good fracture and burn.
9/27/95	6	9	II		na	Good fracture and burn.
9/27/95	7	9	II		na	Press malfunction. Inadequately fractured grenades dumped to furnace. Five grenades exploded in furnace and one unexploded grenade was ejected from furnace. Ejected grenade removed from test site by DPG EOD personnel.
10/12/95	8	16	II	10	140	Added fragment cart water flush prior to dump to furnace. Good fracture and burn.
10/18/95	9	2	I	10	na	Demo test for U.S. Army observer. Good fracture and burn.
10/19/95	10	16	II	10	131	Added furnace grate screen. Good fracture and burn.
10/19/95	11	16	II	10	133	Good fracture and burn.
10/19/95	12	16	II	10	145	Good fracture and burn.
10/19/95	13	16	II	10	139	Good fracture and burn.
10/23/95	14	16	II	10	129	Good fracture and burn.
10/23/95	15	16	II	10	120	Good fracture and burn.
10/23/95	16	16	II	10	126	Good fracture and burn.
10/23/95	17	16	II	10	131	Good fracture and burn.
10/23/95	18	16	II	10	131	One larger than detonator only explosion during furnace burning. No damage.
10/23/95	19	16	II	10	119	One larger than detonator only explosion during furnace burning. No damage.
10/24/95	20	16	II	10	123	Good fracture and burn.

Table 8
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown Time, min.	Fracture Load, tons	Comments
10/24/95	21	16	II	10	139	One larger than detonator only explosion during furnace burning. No damage.
10/24/95	22	16	II	10	116	One larger than detonastor only explosion during furnace burning knocked furnace grate screen off. Minor grate damage and one small fragment penetration of grate screen. Screen replaced on grate. No grate repair required.
10/25/95	23	12	II	10	na	Good fracture and burn.
10/25/95	24	12	II	10	na	Changed fragment cart flush from after to before tooling dump. Good fracture and burn.
10/25/95	25	12	II	10	na	One larger than detonastor only explosion during furnace burning knocked furnace grate screen off. No screen fragment penetrations. Minor grate damage. Grate screen modified and firmly attached to grate.
10/26/95	26	12	II	10	na	Good fracture and burn.
10/26/95	27	12	II	10	na	Good fracture and burn.
10/26/95	28	12	II	10	na	One larger than detonator only explosion during furnace burning. No damage.
10/26/95	29	6	II	11.5	na	One larger than detonator only explosion during furnace burning. No damage.

All tests used a 2.00 in. press closure spacing
Tests 6-29 used zero side-to-side grenade spacing
Tests 4-7 used 0.5 in. end-to-end grenade spacing. Tests 8-29 used zero end-to-end grenade spacing.

Table 9
Test results summary - live M61 hand grenades

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade Spacing (side x end)	Fragment Cart Flush, gal	Purpose of Test	Fracture Load, tons	Comments
10/3/95	1	1	I	20	1.7	Yes	na	0.0	Establish press spacing	na	Grenade exploded during debris burn. Minor damage to grate. No repair required.
10/3/95	2	1	I	20	1.46	Yes	na	0.0	Establish press spacing	na	Improved accessing. Good debris burn.
10/10/95	3	1	I	60	1.46	Yes	na	0.0	Establish press spacing	na	No improvement in spring breakup. Good debris burn.
10/10/95	4	1	I	20	1.20	Yes	na	0.0	Establish press spacing	na	Good accessing. One larger than detonator only explosion immediately following dump into furnace. No damage.
10/11/95	5	1	I	20	.95	Yes	na	1.0	Establish press spacing	na	Added fragment cart water flush prior to dump to furnace. Good fracture and debris burn.
10/11/95	6	2	I	20	1.20	Yes	na x 1/2	1.0	Repetition at selected press spacing	na	One larger than detonator only explosion during debris burn. Debris expelled from grate. No damage.
10/11/95	7	2	I	20	1.20	Yes	na x 1/2	1.0	Repetition at selected press spacing	na	Good fracture and debris burn.
10/11/95	8	2	I	20	1.20	No	na x 1/2	1.0	No LN_2 in basket	na	Inadequate accessing. Both grenades exploded during debris burn. Damaged grate replaced.
10/12/95	9	2	I	15	1.20	Yes	na x 1/2	1.0	Establish cooldown time	na	Good fracture and debris burn.
10/12/95	10	2	I	10	1.20	Yes	na x 1/2	1.0	Establish cooldown time	na	One larger than detonator only explosion during debris burn. No damage.
10/18/95	11	2	I	8	1.20	Yes	na x 1/2	0.0	Establish cooldown time	na	One larger than detonator only explosion during debris burn. No damage.
10/18/95	12	2	I	6	1.20	Yes	na x 1/2	1.5	Establish cooldown time	na	Less breakup of grenades. One larger than detonator only explosion during debris burn. Damaged grate replaced.
10/18/95	13	2	I	10	1.20	Yes	na x 1/2	1.0	Repetition at selected cooldown time	na	Good fracture and debris burn.

Table 9
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade Spacing (side x end)	Fragment Cart Flush, gal	Purpose of Test	Fracture Load, tons	Comments
10/26/95	14	2	I	10	1.20	Yes	na x 1/2	2.5	Repetition at selected cooldown time	na	Changed fragment cart flush from after tooling dump to before tooling dump. Added furnace grate screen before test. Good fracture and debris burn.
10/26/95	15	1	I	10	1.20	Yes	na	2.5	Destruction of extra grenade	na	Good fracture and debris burn.
10/26/95	16	9	II	10	1.20	Yes	1 x 1/2	2.5	Establish minimum grenade spacing	183	Three larger than detonator only explosions during debris burn. No damage.
10/30/95	17	9	II	10	1.20	Yes	1/2 x 1/2	2.5	Establish minimum grenade spacing	188	One larger than detonator only explosion during debris burn. No damage.
10/30/95	18	9	II	10	1.20	Yes	1/4 x 1/2	2.5	Establish minimum grenade spacing	186	One larger than detonator only explosion during debris burn. No damage.
10/30/95	19	9	II	10	1.20	Yes	zero x 1/2	2.5	Establish minimum grenade spacing	181	Less breakup of grenade bodies. Two larger than detonator only explosions during debris burn. Minor grate damage. No repair required.
10/30/95	20	9	II	10	1.20	Yes	1/2 x zero	2.5	Establish minimum grenade spacing	233	Two larger than detonator only explosions during debris burn. Damaged grate replaced.
10/31/95	21	9	II	10	1.20	Yes	1/2 x 1/2	2.5	Repetition at selected grenade spacing	186	One larger than detonator only explosion during debris burn. No damage.
10/31/95	22	9	II	10	1.20	Yes	1/2 x 1/2	2.5 (initial flush)	Repetition at selected grenade spacing	181	Immediate tooling dump following fracture produced freezing of flush water in fragment cart. Four fragment cart flushes required to dislodge all frozen debris. One larger than detonator only explosion during debris burn. Minor grate damage. No repair required.
10/31/95	23	12	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	212	Fragment cart flush eliminated. One larger than detonator only explosion during debris burn. Damaged grate repaired with old grate material.
10/31/95	24	12	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	258	Two larger than detonator only explosions during debris burn. Damaged grate replaced.
10/31/95	25	8	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	168	Good fracture and debris burn.

Table 9
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade Spacing (side x end)	Fragment Cart Flush, gal	Purpose of Test	Fracture Load, tons	Comments
10/31/95	26	8	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	157	One larger than detonator only explosion during debris burning. No damage.
10/31/95	27	8	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	168	One larger than detonator only explosion during debris burn. No damage. Fire in fragment cart (at grate dump) followed by a larger than detonator only explosion in the cart. Fragment cart damaged.
11/02/95	28	8	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	181	Good fracture and debris burn.
11/02/95	29	9	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	200	One larger than detonator only explosion immediately following dump to furnace. Minor grate damage. No repair required. Fire in fragment cart (at grate dump) followed by a larger than detonator only explosion in the cart. No fragment cart damage.
11/02/95	30	9	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	194	One larger than detonator only explosion during debris burn. Minor grate damage. No repair required.
11/02/95	31	9	II	10	1.20	Yes	1/2 x 1/2	0.0	Large quantity cryofracture	191	Good fracture and debris burn.
11/15/95	32	1	I	10	0.94	Yes	na	0.0	Reduced press closure spacing	na	Excellent fragmentation coil breakup. Good debris burn.
11/15/95	33	1	I	10	0.94	Yes	na	0.0	Repeat of Test 32	na	Handling basket tipped over before fracture. Fragmentation coil stayed intact. One larger than detonator only explosion during debris burn. No damage.
11/15/95	34	1	I	10	0.94	Yes	na	0.0	Repeat of Test 32	na	Fragmentation coil mangled but not broken. Good debris burn.
11/15/95	35	1	I	10	0.94	Yes	na	0.0	Repeat of Test 32	na	Excellent fragmentation coil breakup. Detonator in two pieces. Good debris burn.
11/15/95	36	1	I	10	0.94	Yes	na	0.0	Repeat of Test 32	na	Good fragmentation coil breakup. Good debris burn.

Table 9
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade Spacing (side x end)	Fragment Cart Flush, gal	Purpose of Test	Fracture Load, tons	Comments
11/16/95	37	1	I	10	0.76	Yes	na	0.0	Reduced press closure spacing	134	Good fragmentation coil breakup. Good debris burn.
11/16/95	38	1	I	10	0.76	Yes	na	0.0	Repeat of Test 37	100	Good fragmentation coil breakup. Good debris burn.
11/16/95	39	1	I	10	0.76	Yes	na	0.0	Repeat of Test 37	87	Excellent fragmentation coil breakup. Good debris burn.
11/16/95	40	3	II	10	0.94	Yes	na x 1/2	0.0	Increased quantity at reduced press closure spacing	156	Good breakup of two fragmentation coils. Third fragmentation coil distorted but not broken. Good debris burn.
11/16/95	41	9	II	10	0.94	Yes	1/2 x 1/2	0.0	Increased quantity at selected conditions	278	Two larger than detonator only explosions during debris burn. No damage.
11/16/95	42	9	II	10	0.94	Yes	1/2 x 1/2	0.0	Repeat Test 41	274	Two larger than detonator only explosions during debris burn. No damage.
11/20/95	43	9	II	10	0.94	Yes	1 x 1/2	0.0	Increased spacing between grenades	251	One larger than detonator only explosion on furnace grate during debris burning. No grate damage. A fire in the fragment cart produced a larger than detonator only explosion in the cart as the cart approached its home position under the press discharge chute. The fragment cart and a wood building partition were damaged. Fragment cart modified to improve debris discharge at furnace.
12/4/95	44	1	I	10	0.62	Yes	na	0.0	Reduced press closure spacing	na	Excellent fragmentation coil breakup. Most of debris held together by handling basket. Excellent debris discharge from fragment cart. One slightly larger than detonator only explosion during debris burning. No damage.
12/4/95	45	1	II	10	0.62	Yes	na	0.0	Repeat of Test 44	na	Excellent fragmentation coil breakup. Good debris burn.
12/4/95	46	1	II	10	0.62	Yes	na	0.0	Repeat of Test 44	na	Evidence of small explosion during fracture - debris ejected from tooling during fracture and post test odor of burned explosive in test building. Good debris burn.

Table 9
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade Spacing (side x end)	Fragment Cart Flush, gal	Purpose of Test	Fracture Load, tons	Comments
12/4/95	47	3	II	10	>0.75	Yes	na x 1/2	0.0	Increased quantity at new selected closure spacing	na	One larger than detonator only explosion on furnace grate during debris burning. No damage.
12/5/95	48	3	II	10	<0.75	Yes	na x 1/2	0.0	Repeat Test 47 with revised press setup	344	Good fracture and debris burn.
12/5/95	49	3	II	10	0.88	Yes	na x 1/2	0.0	Increased press closure spacing	236	One larger than detonator only explosion on furnace grate during debris burning. Minor grate damage. No repair required.
12/5/95	50	6	II	10	0.89	Yes	1 x 1/2	0.0	Increased quantity at selected press closure spacing	369	One larger than detonator only explosion on furnace grate during debris burning. No damage.
12/5/95	51	9	II	10	1.12	Yes	1 x 1/2	0.0	Determine fracture tonnage at new closure spacing	295	One larger than detonator only explosion on furnace grate during debris burning. Minor grate damage. No repair required.
12/5/95	52	9	II	10	1.09	Yes	1 x 1/2	0.0	Determine fracture tonnage at new closure spacing	348	Two larger than detonator only explosions on furnace grate during debris burning. Damaged grate repaired.
12/5/95	53	9	II	10	1.00	Yes	1 x 1/2	0.0	Determine fracture tonnage at new closure spacing	494	One larger than detonator only explosion on furnace grate during debris burning. No damage.
12/5/95	54	9	II	10	1.09	Yes	1 x1/2	0.0	Repeat Test 52	379	One larger than detonator only explosion on furnace grate during debris burning. Minor grate damage. No repair required.
12/5/95	55	9	II	10	1.07	Yes	1 x 1/2	0.0	Repeat Test 52	368	One larger than detonator only explosion on furnace grate during debris burning. No damage.
12/6/95	56	9	II	10	1.10	Yes	1 x 1/2	0.0	Repeat Test 55 with reduced furnace temp.	398	Below grate furnace temp. reduced to ~1200°F.One larger than detonator only explosion on furnace grate during debris burning. No damage.

Table 9
(cont)

Test Date	Test No.	No. of Grenades	Basket Type	Cooldown time, min	Press Closure Spacing, in	LN_2 in Basket?	Grenade Spacing (side x end)	Fragment Cart Flush, gal	Purpose of Test	Fracture Load, tons	Comments
12/6/95	57	9	II	10	~1.10	Yes	1 x 1/2	2.5	Repeat Test 56 with fragment cart flush	426	Added fragment cart flush after tooling dump. Evidence of small explosion during fracture - debris ejected from tooling during fracture and post test odor of burned explosive in test building. No damage. Good debris burn.
12/6/95	58	9	II	10	~1.10	Yes	1 x 1/2	2.5	Repeat Test 57	413	One larger than detonator only explosion on furnace grate during debris burning. No damage.
12/6/95	59	9	II	10	1.11	Yes	1 x 1/2	2.5	Repeat Test 57 with modified handling basket shoring	443	Two larger than detonator only explosions on furnace grate during debris burning. Minor grate damage. No repair required.
12/6/95	60	9	II	10	1.07	Yes	1 x 1/2	2.5	Repeat Test 59 with no LN2 in basket	467	Four larger than detonator only explosions on furnace grate during debris burning. Minor grate damage. No repair required.
12/6/95	61	5	II	10	~1.00	Yes	1 x 1/2	na	Repeat Test 57 with remaining grenades	unknown	Explosion in press tooling during fracture. Minor tooling damage. Also damage to press honeycomb structure, press discharge chute,fragment cart, and lower level building rollup door.

Table 10
Munitions handling concept comparison

	Advantages	Disadvantages
Concept 1	• Uses less complex (hard automation) equipment for munitions handling • Requires less equipment maintenance	• Requires design, fab, and use of first-of-a-kind press loading equipment • Difficult to minimize out-of-cryobath warmup time for munitions • No experience with moving munitions through cryobath while cooling • No error recovery capability
Concept 2	• Programmable automation provides greater flexibility to handle new types of munitions and to perform new remote operations • GA has extensive experience with overhead robots • Provides error recovery • Costs assume availability of an existing overhead robot from chemical weapons demil program	• Requires maintenance of robot equipment and controller • Cost penalty if existing overhead robot cannot be used

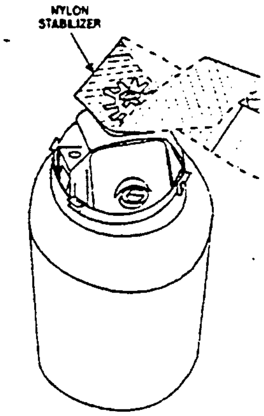
REFERENCES

1. GA - C22002 (6/95), Test Plan - Cryofracture Demilitarization of Munitions

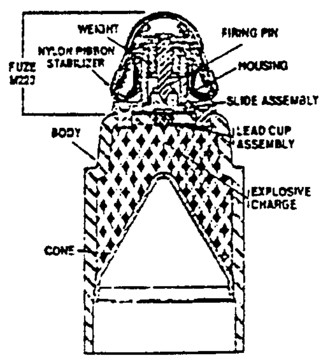
2. GA Document 219003, Safety Assessment/Preliminary Hazard Analysis - Cryofracture Demilitarization of Munitions

APPENDIX A
TM 43-0001 MUNITIONS DATA SHEETS

GRENADE: GENERAL PURPOSE, M42



SIDE VIEW



CROSS SECTION

U
AR 101395

Type Classification:

Use:

To provide anti-materiel and anti-personnel capabilities in a submissile delivered by 155mm M483 and 8-inch M509 projectiles for howitzers.

Description:

The M42 grenade is a ground burst munition consisting essentially of a 1.5 inch diameter cylindrical shell body loaded with approximately 31 grams of Composition A5 in a shaped charge. A nylon ribbon loop stabilizer is provided to orient and arm the grenade.

The inertia type fuze has a slide assembly containing an M55 detonator and a coil spring to force the slide into the armed position.

The M42 grenade has embossed inner side wall for optimum fragment size.

Classification:

Standard A.

Tabulated Data:

Explosive	30.5 grams Comp A5
Length	3.25 in.
Weight	0.46 lb

Functioning:

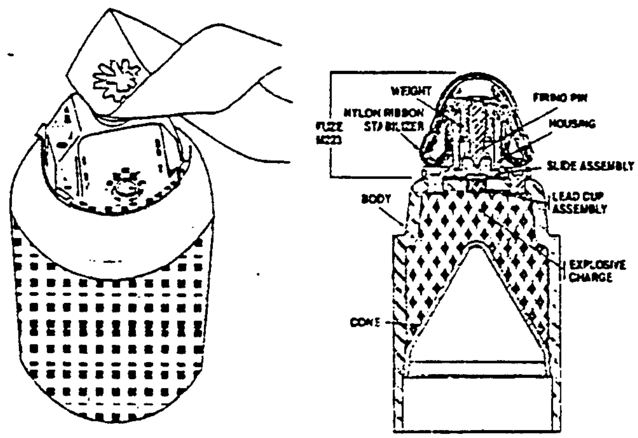
Upon expulsion from the projectile, the nylon ribbon stabilizer extends and orients the grenade, and due to rotational forces, unthreads the threaded firing pin from the weight (semi-armed), and pulls the firing pin out of the slide assembly. The slide assembly is then free to move, and moves into the armed position by action of the slide spring and centrifugal force. The spring maintains the slide assembly in the fully armed position.

Upon impact, the inertia weight drives the firing pin into the detonator M55, initiating the firing train. A shaped-charge jet is expelled downward while the body bursts into a large number of small fragments. The jet is capable of penetrating approximately 2.75 inches of homogeneous armor plate. Antipersonnel effects are obtained by fragmentation of the grenade body.

Drawing:

Grenade 9215340

GRENADE: GENERAL PURPOSE, M46



SIDE VIEW

CROSS SECTION

U
AR 101386

Type Classification:

Use:

To provide antimateriel and antipersonnel capabilities in submissiles carried in the last three aft layers in the 155MM M483 projectile for howitzers.

Description:

The M46 grenade is a ground burst munition consisting essentially of a 1.5 inch diameter cylindrical shell body loaded with approximately 30 grams of Comp A5 in a shaped charge. A nylon ribbon loop stabilizer is provided to orient and arm the grenade. The inertia type fuze has a slide assembly containing a M55 detonator and a coil spring to force the slide into the armed position. The M46 grenade has a smooth inner side wall that makes the body wall stronger than the embossed wall of the M42 grenade. The wall does not have optimum fragmentation characteristics of the M42 grenade wall, but has extra strength to prevent compression failure during setback.

Classification:

Standard A.

Tabulated Data:

Explosive	30 g Comp A5
Length	3.25 in.
Weight	0.47 lb

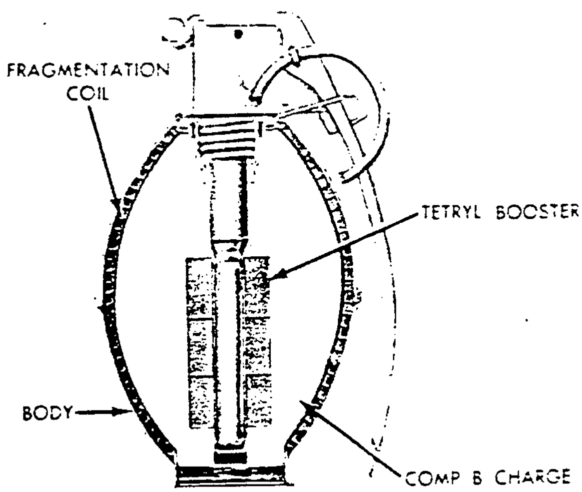
Functioning:

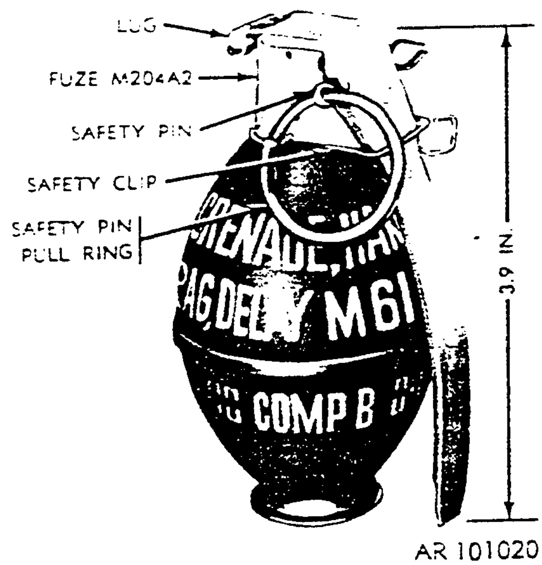
Upon expulsion from the projectile, the nylon ribbon stabilizer extends and orients the grenade, and due to rotational forces, unthreads the threaded firing pin from the weight (semi-armed), and pulls the firing pin out of the slide assembly. The slide assembly is then free to move, and moves into the armed position by action of the slide spring and centrifugal force. The spring maintains the slide assembly in the fully armed position.

Upon impact, the inertia weight drives the firing pin into the M55 detonator, initiating the firing train. A shaped-charge jet is expelled downward while the body bursts into a large number of small fragments. The jet is capable of penetrating approximately 2.75 inches of homogeneous armor plate. Antipersonnel effects are obtained by fragmentation of the grenade body.

Drawing:

Grenade 9215370





Type Classification:

Std. LCC-A, AMCTC 6446

Use:

The M61 fragmentation hand grenade is used to supplement small arms fire against the enemy in close combat. The grenade produces casualties by high velocity projection of fragments.

Description:

Each grenade is assembled with a fuze that initiates the explosive charge. These grenades detonate 4 to 5 seconds after release of the safety lever.

Hand grenade M61 incorporates a safety clip. The body is constructed of two pieces of thin-wall sheet steel and has a notched fragmentation coil liner.

M61 hand grenade uses M204A1 or M204A2 fuzes. They are pyrotechnic delay detonation fuzes. They differ only in body construction. The body contains a primer and a pyrotechnic delay column. Assembled to the body are a striker, striker spring, safety lever, safety pin with pull ring, and a detonator assembly. The split end of the safety pin has an angular spread.

The hand grenade safety clip is designed to keep the safety lever in place should the safety pin be unintentionally removed from the grenade. It is an additional safety device used in conjunction with the safety pin.

The safety clip, of spring steel wire, consists of a loop which fits around the fuze body and a clamp which fits over the safety lever.

Tabulated Data:

Grenade (with fuze):	
Model	M61
Body	Thin-wall sheet steel w/ inner fragmentation coil
Weight	16 oz
Length (max)	3.9 in.
Diameter	2.25 in.
Color	Olive drab w/yellow markings
Packing	1 per fiber container; 30 per packing box
Explosive Filler:	
Type	Comp B w/tetryl pellets
Weight:	
Comp B	5.5 oz
Tetryl pellets	0.3 oz
Fuze:	
Model(s)	M204A1, M204A2
Type	Pyrotechnic delay-detonating
Primer (percussion)	M42
Detonator	Lead azide, lead styphnate, and RDX
Delay time	4 - 5 sec
Weight	2.6 oz
Length	4 in.
Color, safety lever	Olive drab w/black markings
Packing	Not issued separately

Federal Supply Code:

NSN ------------------------	1330-00-935-6064
DODAC -------------------	1330-G880

See DOD Consolidated Ammunition Catalog for additional information.

Unit of Issue:

Each Packed -----------	1 per fiber container; 30 per packing box.

Packing Data:

Packing box:	
Weight (with contents) -------------	53.0 lb
Dimensions -----------	19-7/16 in. x 11-3/8 in. x 12-23/32 in.
Cube --------------------	1.60 cu ft

Shipping and Storage Data:

Hazard class/division and storage compatibility group-	(04) 1.1F
UNO serial number --	0292
DOT class ---------------	Class A explosive
DOT marking ---------	HAND GRENADES

Functioning:

Release of the safety clip and removal of the safety pin permit release of the safety lever. When the safety lever is released, it is forced away from the grenade body by a striker acting under the force of a striker spring. The striker rotates on its axis and strikes the percussion primer. The primer emits a small, intense spit of flame, igniting the delay element. The delay element burns for 4 to 5 seconds, then sets off the detonator. The detonator explodes, thus initiating the explosive charge. The explosive charge explodes, rupturing the body and projecting fragments.

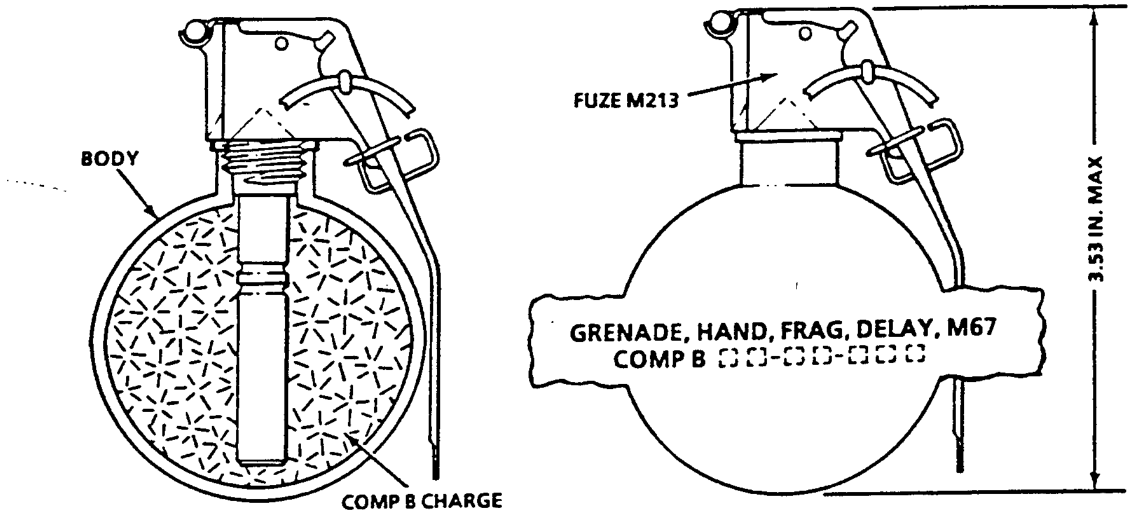
References:

TM 9-1330-200-12
TM 9-1330-200-34
FM 23-30
DOD Consolidated Ammo Catalog

Drawings:

Assembly ----------------	9231594
Fuze:	
M204A1 -----------------	82-1-87
M204A2 -----------------	7548570
Packing (inner) --------	7548339
Packing (outer) --------	7548340

GRENADE, HAND: FRAGMENTATION, DELAY, M67



AR 101021-A

Type Classification:

Std. LCC-A, AMCTC 7764

Use:

The M67 fragmentation hand grenade is used to supplement small arms fire against the enemy in close combat. The grenade produces casualties by high velocity projection of fragments in a uniform distribution pattern.

Description:

The grenade body is a 2.5-inch diameter steel sphere which is designed to burst into numerous fragments when detonated. The grenade body contains 6.5 ounces of high-explosive, Composition B. Each grenade is fitted with a fuze that initiates the explosive charge.

The M67 grenade uses the M213 fuze which is a pyrotechnic delay-detonating fuze. It will function the grenade 4 to 5 seconds after release of the safety lever. The body of the fuze contains a primer and a pyrotechnic delay column. Assembled to the body are a striker, striker spring, safety lever, safety pin and pull ring, safety clip, and a detonator assembly.

The M213 fuze is equipped with a steel safety pin and pull ring. The split end of the safety pin is either spread approximately 40 degrees or diamond-shaped to prevent accidental removal and arming during shipping and handling. The pull ring is provided to facilitate easy removal of the safety pin.

A second safety feature is the steel safety clip. The safety clip's purpose is to prevent the safety lever from snapping upward into a triggered position, in the event the safety pin is accidentally dislodged from the fuze.

Tabulated Data:

Grenade (with fuze):	
Model	M67
Body	Steel
Weight	14 oz
Length (max)	3.53 in.
Diameter	2.5 in.
Color	Olive drab w/yellow markings
Explosive filler	
Type	Comp B
Weight	6.5 oz
Fuze:	
Model	M213
Type	Pyrotechnic delay-detonating
Primer (percussion)	M42
Detonator	Lead azide, lead Styphnate, and RDX
Delay time	4 - 5 sec
Weight	2.5 oz
Length	3.33 in.
Color, safety lever	Olive drab w/black markings
Safety device(s)	Pull ring and safety pin, and safety clip.

Federal Supply Code:

NSN ---------------------------- 1330-00-133-8244
DODAC ----------------------- 1330-G881

See DOD Consolidated Ammunition Catalog for additional information.

Unit of Issue:

Each Packed: --------------- 1 per fiber container; 30 per wooden box

Packing Data:

Packing box:
- Weight (with contents) - 52.0 lb.
- Dimensions --------------- 18-15/16 in. x 11-1/4 in. x 11-1/16 in.
- Cube ------------------------ 1.37 cu ft
- Explosive weight -------- 12.2 lb

Shipping and Storage Data:

Hazard class/division and storage compatibility group ---------------------	(04) 1.1F
UNO serial number -----	0292
DOT class ------------------	Class A explosive
DOT marking -----------	HAND GRENADES

Functioning:

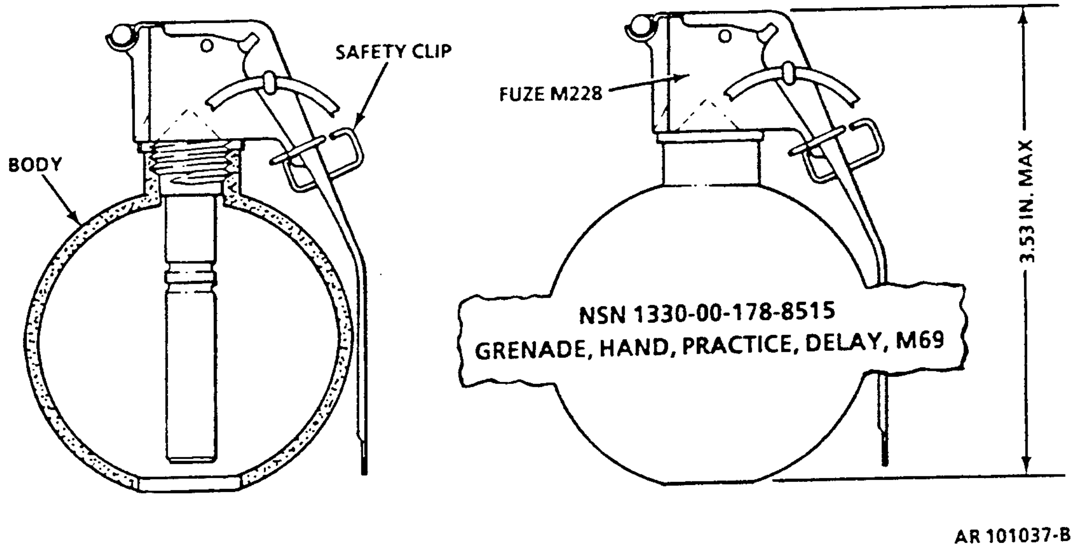
Release of the safety clip and removal of the safety pin permits release of the safety lever. When the grenade is thrown, the striker assembly, through action of the spring, throws off the safety lever and impacts the percussion primer which functions the primer charge. The primer charge ignites the delay composition which will burn approximately 4-5 seconds. Upon completion of burning, the delay composition sets off the detonator which ignites the main explosive charge and detonates the grenade.

References:

TM 9-1330-200
TM 9-1330-200-12
TM 9-1330-200-34
FM 23-30
DOD Consolidated Ammo Catalog

Drawings:

Top Drawing:	9235492
Marking drawing:	8810742
Packing box:	9288720
Fiber container:	8800493



Type Classification:

Std, LCC-A, AMCTC 8345

Use:

Delay practice hand grenade M69 is the practice version of the M67 fragmentation delay grenade.

Description:

The grenade body, of steel, is essentially spherical in shape. The body is empty, i.e., without any explosive filler. There is a hole in the base of the body. (This vents the gases generated from the fuze igniter and permits removal of residual metal that remains in the grenade body from the igniter case. The grenade body may be recovered and reloaded with a new fuze and safety clip).

Hand grenade practice fuze M228 is a pyrotechnic delay-igniting fuze. The body contains a primer and a pyrotechnic delay column. Assembled to the body are a striker, striker spring, safety lever, safety pin with pull ring, safety clip, and igniter assembly. (Older models do not have the safety clip). The split end of the safety pin has an angular spread or a diamond crimp.

The hand grenade safety clip is designed to keep the safety lever in place, should the safety pin be unintentionally removed from the grenade. It is an additional safety device used in conjunction with the safety pin. The safety clip is assembled to the fuze. (Older models have the safety clip assembled to the grenade and positioned around the safety lever).

Safety clips from expended grenades may be reused, provided that visual examination indicates the clip is not damaged or distorted.

Tabulated Data:

Grenade (with fuze):

Model	M69
Body	Steel
Weight	14 oz
Length (max)	3.53 in.
Diameter	2.5 in.
Color	Blue w/brown band and white markings

Filler:
Type ---------------------------- None
Weight ------------------------- None

Fuze:
Model ------------------------- M228
Type --------------------------- Pyrotechnic delay-igniting
Primer ------------------------ M42
Igniter ------------------------ Black powder
Delay time ----------------- 4.5 sec
Weight ---------------------- 2.5 oz
Length ---------------------- 3.33 in.
Color (safety lever) ----- Blue w/brown end and black markings
Packing -------------------- 360 per box
Safety device ------------ Pull ring and safety pin, and safety clip

*Packing Data:

Grenade bodies -------- 50 per carton: 1 carton per barrier bag: 1 barrier bag per wooden box
Grenade fuzes -------- 45 per tray; 8 trays (360 fuzes) per wooden box

Packing box:
Weight (with grenade bodies) -------------------- 68.5 lb
Dimensions --------------- 18 x 15 x 8 in.
Cube ------------------------- 1.5 cu ft
Explosive weight ------ None

*See DOD Consolidated Ammunition Catalog for additional information.

Shipping and Storage Data:

Hazard class/division and storage compatibility group ----------- 1.4 G
UNO serial number ----- 0372
DOT class ------------------- Class C explosive
DOT marking ------------ TIME FUZES - HANDLE CAREFULLY

DODAC (Grenade, assembled) ---- 1330-G918
DODAC (Grenade fuze) --------------- 1330-G878

Functioning:

Release of the safety clip and removal of the safety pin permit release of the safety lever. When the safety lever is released, it is forced away from the grenade body by a striker acting under the force of a striker spring. The striker rotates on its axis and strikes the percussion primer. The primer emits a small, intense spit of flame, igniting the delay element. The delay element burns for 4 to 5 seconds, then sets off the igniter. A loud report, like that of a firecracker, and a puff of white smoke follows.

Drawings:

Assembly ----------------- 9235208
Fuze ------------------------- 9235210

Remarks:

The M69 practice hand grenade is normally issued as separate components, as required. Component parts consist of a practice hand grenade body and a practice hand grenade fuze.

References:

TM 9-1330-200-12
TM 9-1330-200-34
FM 23-30
DOD Consolidated Ammo Catalog

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